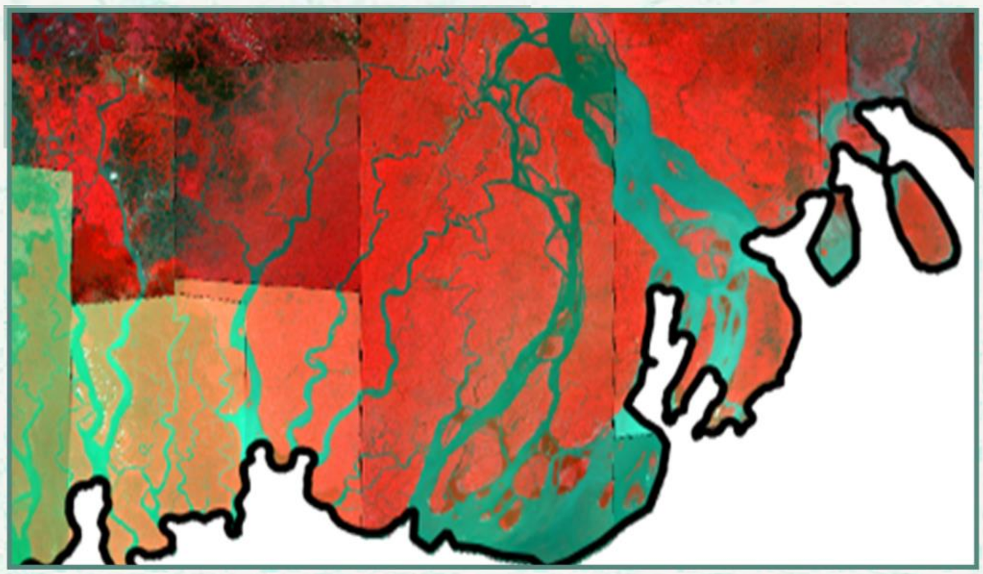
# Land cover and forest monitoring in Bangladesh



**Bangladesh Forest Department**

**February 2016**

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Food and Agriculture Organization of the United Nations

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The Forest Department of Bangladesh leads actions to improve forest management and conservation, adopting forward thinking, innovative approaches in its management of approximately 1.55 million hectares of land across the country.

In 2015, the Forest Department began a process to establish a National Forest Inventory and Satellite Land Monitoring System for improved forest and natural resource management. The process addresses domestic information needs and supports national policy processes related to forests and the multitude of interconnected human and environmental systems that forests support. The process also supports climate change mitigation and implementation of REDD+.

The Bangladesh Forest inventory, led by the Forest Department, is a constant and comprehensive process that assesses, evaluates, interprets and reports on the status of trees and forest resources nationally. The activities implemented under the Bangladesh Forest Inventory process are implemented in collaboration between several national and international institutions and stakeholders. National partners from multiple government departments and agencies assist in providing a nationally coordinated approach to land management. International partners, including the United Stated Agency for International Development (USAID), the Food and Agriculture Organization of the United Nations (FAO) and SilvaCarbon are supporting the development of technical and financial resources that will assist in institutionalizing the process.

The results will allow the Forest Department to provide regular, updated information about the status of trees and forests for a multitude of purposes including for assessment of role of trees for firewood, medicines, timber, and climate change mitigation.

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# Executive Summary


Forest and land cover monitoring system have been rarely integrated together for several reasons including historical, cultural, institutional arrangements, available human, financial and technical resources allocated to monitoring forest and natural resources in general. While the responsibility to monitor and assess the status of natural resources is being given to a multitude of national government institutions, the collaboration between them is often limited by the way natural resources are being represented for different interests or by different cultural background. Ensuring the consistency between the data provided by different institutions with the same aim but with different objectives has always been a problem.

With the recent launch of the new Land cover classification system, a new way to represent our environment offer us the possibility to develop products that are integrated. In addition, national institutional frameworks to deal with the management of forest and natural resources is constantly evolving and improving in order to adapt to the existing and emerging demand form the society. While Bangladesh is committed to upgrade the land cover and forest monitoring system, the collaboration of several national institutions allow the development of an integrated and cost-efficient system to meet different objectives of the different institutions, the consistency between the different data produced, their transparency to allow their improvement in the future etc.

The objective of this document is to present the methodology used for the national land cover map development and the national forest monitoring system. It is the result of the collaboration between several national and international institutions supported by several projects. It aims to be a living document that can be updated and to be the basis of further land cover map development in Bangladesh.

The first section provides information regarding the context of land cover and forest mapping in Bangladesh followed by a brief overview of land cover mapping initiatives in the second section. Section three outlines the methodological outline for the land cover mapping and forest monitoring. Ancillary information are provided in appendix.

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# Acronyms

| | |
|---|---|
| AD | Activity Data |
| AFOLU | Agriculture forestry and other land uses |
| FAO | Food and Agriculture Organization of the United Nations |
| FD | Forest Department |
| FIGNSP | Forest Information Generation & Networking System Project |
| GHG | Greenhouse gases |
| LCCS | Land cover classification system |
| LCML | Land Cover Meta Language |
| LULUCF | Land use, land-use change and forestry |
| MRV | Measuring, Reporting and Verification |
| REDD+ | Reducing emissions from deforestation and forest degradation and the role of conservation, sustainable management of forests and enhancement of forest carbon stocks in developing countries |
| RIMS | Resources Information Management System |
| SRDI | Soil Resource Development Institute |
| UMD | University of Maryland |
| UNFCCC | United Nations Framework Convention on Climate Change |

# 1. Introduction

The main goal of national natural resource management programs is to lead and steer policy development and implementation processes in an inter-sectorial way (FAO, 2006). National forest monitoring systems contribute to forest programs and natural resource management programs through monitoring forest changes, and forest services, over time (FAO, 2013). On the other hand, national forest programs benefits from a multitude of data and information from other natural resource monitoring systems.

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. There is a need for spatially explicit data describing land cover, uses and management practices to recognize and characterize the heterogeneity of country's land, water and vegetation resources.

To do so, national institutions are collecting and analysing natural resources and forest-related data and provide knowledge and recommendations at regular intervals. The way data are collected and analysed change over time in Bangladesh and in all countries. The collection of those data and their analyses have continually evolved with technological and computational advances (Kleinn, 2002). For instance, tree ground measurements, such as diameter or height measurements, which were typically measured with measuring tape or forest compasses and relascopes, are now enhanced with new technologies, such as laser rangefinders. Furthermore, remote sensing is being increasingly used to improve ground sampling strategies (McRoberts), to calculate forested land area and area changes (Hansen et al., 2013a; INPE, 2006, 2008), and to detect many variables of interest such as fires, pest outbreaks, or trees outside forests (Barducci et al., 2002). The use of remotely sensed data together with ground-based observations has gained a lot of attention for modeling and validating greenhouse gas (GHG) emissions and removals associated with forests, particularly in the context of REDD+ (GFOI, 2014; GOFC-GOLD, 2010).

During the last decades in Bangladesh, several governments, autonomous as well as private or trustee organisations were engaged in land cover/land use mapping, at different levels, by making use of remote sensing and ancillary data (Akhter & Shaheduzzaman, 2013). Akhter and Shaheduzzaman (2013) have made an inventory of national and sub-national land cover products in Bangladesh. It appears that several national land cover/use maps are developed. But due to differences in organizational purposes, methodologies, boundaries, definitions, classification systems, varying means and capacities, the different land cover maps are not comparable in time and space. Several problems in terms of transparency, accuracy, consistency, completeness and comparability of land cover assessments limit their potential use. Many of the legends used for land cover mapping are not available and the classes are not appropriately described. Accuracy assessment is not performed in most cases. In some cases, the classification system for a single thematic area is not the same for different projects in an organisation itself. In brief, organizational differences are highly manifested not only in the end products but also in the processes involved. In consequence, the use of the different land cover maps and their integration into one system is limited by constraints such as lack of documentation, inconsistency in spatial and temporal resolutions, accessibility, different classification systems, etc.

While several institutions aim at improving the management of natural resources and to contribute to environmental crisis such as climate change, their efforts in assessing the status of the resources is often limited by the multitude of different sources of information providing different results and their quality.

In 2011 Bangladesh became member of the UN-REDD programme and prepared a national REDD+ Readiness Roadmap that was endorsed by the UN-REDD policy board in 2012. The Bangladesh REDD+ Readiness

Roadmap describes a plan of activities which prepare the country fully for the implementation of GHG emission reductions in the forestry sector. When implementing climate change mitigation activities in forestry and for other sectors through international mechanism such as REDD+ (Reducing emissions from deforestation and forest degradation and the role of conservation, sustainable management of forests and enhancement of forest carbon stocks in developing countries) or through national frameworks, it is imperative to ensure that the data are consistent to each other. It is also imperative that the data are properly documented in order to ensure the sustainability of the process and its continuous improvement in order to meet the emerging demands from our society.

In the context of REDD+, in particular, it is imperative to implement a national forest monitoring system that addresses the needs for measuring, reporting and verifying (MRV) emission reduction in forestry and to ensure the consistency between the MRV data and the land cover information used for the LULUCF/AFOLU GHG inventory preparation. According to the UNFCCC Decision 11/CP.19, a robust national forest monitoring system should provide data and information that are transparent, consistent over time, and are suitable for measuring, reporting and verifying anthropogenic forest-related emissions. To this end, the national forest monitoring system should allow the acquisition of data on the extent of human activities in the forestry sector (activity data) for each of REDD+ activities.

Past data are expected to support the identification of baseline scenario (forest reference level (FRL) and forest reference emission levels (FREL) and inform policy makers. Four decisions taken by the COP provide guidance on REDD+ FREL/FRLs. The first decision related to FREL/FRLs (Decision 4/CP.15) states that FREL/FRLs should be established transparently, taking into account historic data, and adjust for national circumstances. Decision 1/CP.16 includes FREL/FRLs as one of the four key elements to be developed, in the context of adequate and predictable support, by countries implementing REDD+ activities. Decision 12/CP.17 provides modalities for FREL/FRLs (or construction guidelines) and, in an annex, includes guidelines for submissions of information on FREL/FRLs to the UNFCCC. Decision 13/CP.19 provides guidelines and procedures for the technical assessment of FREL/FRLs submitted to the UNFCCC.

The current data acquisition should allow monitoring REDD+ activities in line with national objectives and decisions. At current status, few countries explored the possibility to have an integrated system being implemented by different institutions for the land cover and forest map development and for the field data collection. Bangladesh aims at implementing an integrated forest and land cover monitoring and assessment system and there is a multitude of different ways to implement it. However, the number of approaches to estimating forest-related variables from field data, from remote sensing, or from a combination of the two, is striking. A good illustration of the variety of the approaches is the Food and Agriculture Organization of the United Nations' (UN-FAO) Forest Resources Assessment (FAO, 2010) that report 90 variables in all types of forests occurring in 233 countries; with region- or country-specific approaches, variables and efforts.

To account for forest structure 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., 2013a; 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). Such discrepancies may be explained by differences in the definitions of forests, in the forest and land classification systems, in the approaches used to analyse the satellite imagery, or by the field inventory data used: e.g. Hansen et al. (2013a) focused on tree cover canopy while FAO and JRC (2012) focused on forest land use and change. 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. Countries themselves decide what level of detail or classification scheme they wish to use, leading to the above-mentioned huge heterogeneity among national forest systems. Using the FAO Land Cover Classification System (Antonio. Di Gregorio & Jansen, 2005) to label the various identified land cover classes is suggested by GFOI (2014) as a promising option ensuring homogeneity between different country-specific legends and maps.

Management of natural resources is closely dependent on the classification system used to monitor the evolution of the state of environmental resources. Therefore, definitions and classifications are crucial for the assessment of natural resources to evaluate whether policies and measures have positive or negative effects and meet their target(s). A standardized and harmonised classification system for the country is, hence, needed to be identified and defined, for mapping the land cover. The different legends and collected field data should be used to develop a common and functional classification system. The system can, therefore, serve as a dynamic source of information for several different applications and objectives. Such a key-legend applicable to maps, prepared under different modalities, would facilitate the process of comparison, the production of statistics and time-series data. This would also set the basis for the development of a national reference system.

This report is specifically aimed at the following –

1) To describe the existing land cover/use mapping activities
2) To present the methodology for the land cover and forest classification system
3) To present the methodology for the land cover map development
4) To present the methodology for the tree and forest monitoring system

Following the backgrounds provided in this section, section 2 gives an overview of the land cover mapping initiatives starting from the latest one.

# 2. Land cover mapping in Bangladesh

There are several organizations involved in land cover/use maps development at national and sub-national levels for Bangladesh. This section provides an overview of the organizations, methodologies, input data (i.e. field data, satellite images), classification systems, etc. for mapping activities. Following these descriptions is a summary table (**Table 2**) listing the land cover maps developed for different areas in Bangladesh. The illustrations and legends of the existing national land cover and forest maps are available in appendix 1 and 2 respectively.

## 2.1 Land Ministry

The National Land Zoning Project is an ongoing project of the Ministry of Land of the Government of Bangladesh (http://www.landzoning.gov.bd). This national level project is aimed at assigning country's land to its best possible and proper use in order to get maximum economic benefits from lands resolving conflicts of interest. The main expected output of the project is Upazila (sub-district) wise Digital Land Zoning Map with detailed description of present and potential land uses, physical and chemical characteristics of lands; environmental and social issues pertinent to land resources. The resultant land zoning is supposed to be used as an integrated and development-oriented tool for proper planning and management of land resources.

Both primary and secondary data are being used for land zoning. Secondary information (including different types of satellite images, administrative boundaries, roads and highways, etc.) are acquired from different organizations to prepare land use maps. A combination of images of different seasons and field level land use information are used to produce union-wise land use maps. The resulting land use classes are different for different upazilas. Land suitability maps are then derived from data on soils, land type and surface water by using computer software.

Selected land use maps developed under land zoning project (Sl 1 to 3) are presented in Appendix 1.

## 2.2 Forest Department

Forest Department (FD) of the Government of Bangladesh is entrusted with conservation of forests, environment and biodiversity and socio-economic development through modern technology and innovation (http://www.bforest.gov.bd/). Forest expansion, biodiversity conservation, poverty alleviation and wildlife conservation through active participation of people is the mission of FD. Several initiatives have been taken by FD for land cover and forest mapping in Bangladesh in different times. Forest Information Generation & Networking System Project (FIGNSP) and National Forest Assessment (NFA) are the most recent ones among them.

### 2.2.1 Forest Information Generation & Networking System Project

The Forest Information Generation & Networking System Project (FIGNSP) was implemented by the Resource Information Management System (RIMS) Unit, Forest Department (FD) of Bangladesh with the technical assistance of Remote Sensing Division of Center for Environmental and Geographic Information Services (CEGIS). The key objectives of the project were to map forest coverage and related land cover in selected forest areas in Bangladesh. The areas include Sundarban Reserved Forest, Sal Forests, Hill Forests and Coastal afforestation.

1m IKONOS and 5m RapidEye satellite image data, from January 2011 to February 2012, were acquired and used for classification purpose. The locations of the ground reference data were identified based on different spectral patterns of interest identified on images using a visual interpretation method. After image rectification, segmentation based classification were done for all scenes of the project area to derive forest coverage and different land covers from the acquired satellite images. The segmentation settings used were varied from scene to scene. The similar spectral classes were grouped together and labelled with a land cover based on ground reference data. Finally, information classes were derived from the spectral segmentation classes. Furthermore, expert knowledge based check was done to improve the accuracy of the declared information classes.

Three groups of land cover classes were produced for the project areas. One group (under Lot-A) gives a total of 19 land cover classes, other group (under Lot-B) gives a total of 20 land cover classes, whereas the third group (Sundarban Reserved Forest under Lot-A) gives a total of 17 classes. All the classified, generated and some archived datasets were used to compose maps in different scales. Two categories of maps were developed, i.e. Forest Division wise maps with suitable scales and 1:15,000 scale maps for all areas, with the exception for the Sundarban Reserved Forest. In case of the Sundarban Reserved Forest, 1:200,000 and 1:50,000 scale maps were produced.

Land cover maps of FIGNSP are presented in Appendix 1 (Sl 4-17).

### 2.2.2 National Forest and Tree Resources Assessment

Country level National Forest Assessment (NFA) was undertaken for the first time during 2005-07 with the technical assistance of FAO. Topographical sheets of 1: 50,000 scale maps, produced by the Survey of

Bangladesh (SoB), were used to delineate the tracts[1]. Out of a total of 299 tracts systematically distributed throughout the country at an interval of 15 minute latitude and 10 minute longitude, 296 were inventoried (3 tracts were excluded due to inaccessibility). Field data collection comprises multiple functions of forests and trees, covering their socio-economic, environmental as well as productive functions, associated with a wide range of variables.

Landsat TM satellite imageries for the year 2005 were used to identify the land use classes. The country was divided into four parts and the images were accordingly mosaicked. These mosaics were used for visual interpretation of the land use types and on-screen digitization was carried out to separate the classes.

29 land use classes were identified during the collection of the field data. However, in view of the real difficulties (related to spatial and spectral resolution of satellite data) in identifying all the land use types in the maps, it was later agreed to delineate 14 land use classes in the land cover maps. Accuracy was not checked for the classified images. Land use maps were prepared in two different scales, namely 1:1,000,000 (one sheet for the whole cover of Bangladesh) and 1:100,000 (67 sheets for the whole cover of Bangladesh).

NFA map is presented in Appendix 1 (Sl 18).

One important mismatch was found between the classes declared in the report and GIS database as shown in **Table 1**.

**Table 1:** Mismatch of land cover classes between NFA report and NFA GIS database

| Forest/land cover | NFA report | NFA GIS database |
|---|---|---|
| **Agriculture & Rural Settlements with Tree Cover** | Yes | No |
| **Haor & Baor** | Yes | Yes |
| **Highway** | Yes | Yes |
| **Hill Forest** | Yes | Yes |
| **Lake** | Yes | Yes |
| **Mangrove Forest** | Yes | Yes |
| **Mangrove Plantation** | Yes | Yes |
| **Rivers** | Yes | Yes |
| **Rubber Plantation** | Yes | Yes |
| **Sal Forest** | Yes | Yes |
| **Shrubs** | Yes | Yes |
| **Urban Settlement** | Yes | Yes |
| **Hill Forest with Mixed Bamboo** | Yes | No |
| **Large Ponds** | Yes | No |
| **Mango plantation** | No | Yes |
| **Mixed Bamboo** | No | Yes |
| **Rural Settlement, Agriculture & Others** | No | Yes |
| **Shifting Cultivation** | No | Yes |
| **Swamp Forest** | No | Yes |
| **Tea Garden** | No | Yes |
| **Pond** | No | Yes |

[1] FAO's standard layout for tracts, plots and subplots was adopted, where tract represents a square of 1 km x 1 km.

## 2.3 Soil Research Development Institute

Soil Research Development Institute (SRDI) is a government organization under the administrative control of Ministry of Agriculture (http://www.srdi.gov.bd/). The aim of SRDI is to assist in achieving self-sufficiency in food and ensure food security for all through appropriate land & soil management for sustainable as well as environmentally friendly agriculture. It is entrusted to prepare inventory of soils of Bangladesh and generate information for sustainable crop production through improved soil management and preservation of environment.

SRDI has prepared national level land use maps in 1996 and 2004. The database for Bangladesh land use 1996 map was prepared by using the base map of 1989 of Survey of Bangladesh (SoB). River courses and islands were updated from Landsat imageries of 1990. Forest cover map of 1994 of forest department was used to update the land use of the forest areas as well as from Landsat imageries of 1984 and 1990 as mentioned in the land use map of 1996 (SRDI, 1996).

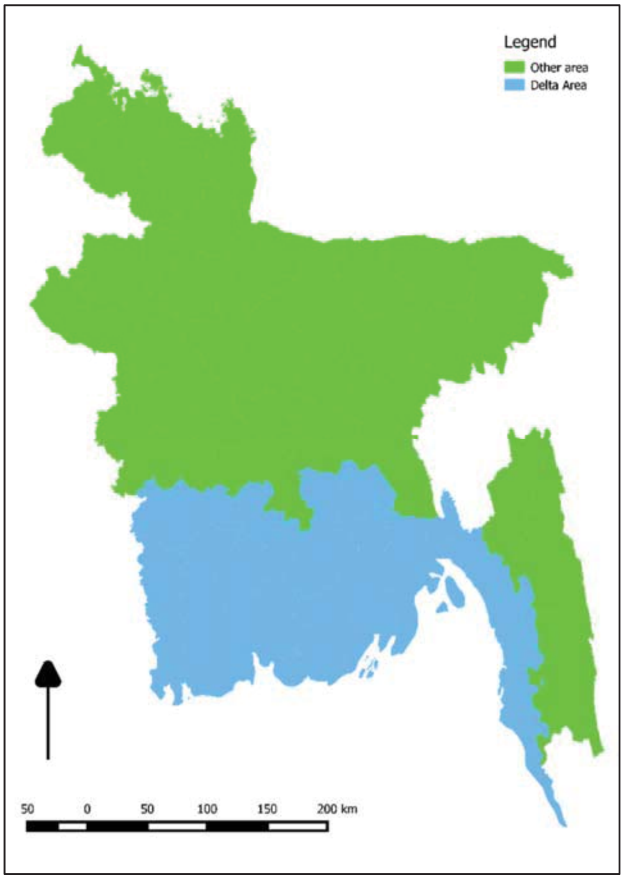
The database for Bangladesh land use 2004 map was prepared using the base map of 2001 of Survey of Bangladesh (SoB). River courses and islands were updated from Landsat imageries of 2004. Information source for the Agriculture land use database was the Land and Soil Resources Development Guide. Forest cover land use database information source was the forest cover map of 1994 of forest department and updated from the Landsat imageries of 1994 and 1990, as stated in the map of land use Bangladesh 2004 (SRDI, 2004).

## 2.4 Center for Environmental and Geographic Information Services

The Center for Environmental and Geographic Information Services (CEGIS) is a Public Trust established by the Government of Bangladesh under the Ministry of Water Resources (MoWR). The working domain of CEGIS span over Resource Management Planning (Natural and Intellectual), System Development, Capacity Building and Research activities (http://www.cegisbd.com/). CEGIS is a scientifically independent organisation and performs integrated environmental analysis using technologies like GIS, RS, IT and databases. It provides solutions to issues and problems in a wide range of sectors, including water, land, agriculture, meteorology, forestry, fisheries, morphology, ecology, environment, climate change, archeology, socio-economy, power, transportation and disasters.

CEGIS works both independently and in close collaboration with government ministries, departments and organizations as well as non-government organisations (NGOs) of the country. It also maintains close cooperation and collaboration with regional and international agencies as well as with foreign nations. Presently CEGIS is involved with the National Land Zoning project of the Ministry of Land. CEGIS with association with Bangladesh University of Engineering and Technology (BUET) is developing the national legend and land cover map of 2015 for the delta area of Bangladesh (19 coastal districts). Forest Department will develop land cover map for the rest of the country. Figure 1 below shows the delta and other area.

**Figure 1:** delta and other area




## 2.5 Survey of Bangladesh

Survey of Bangladesh (SOB) is the national mapping organization of Bangladesh established under the ministry of Defence (http://www.sob.gov.bd/). It is entrusted with national mapping, storage and distribution. The functions of SoB include trigonometrical and geodetic control survey; topographical survey (e.g. preparation of topographical maps for the country at different scales); publishing of geographical and political (administrative) and communication maps; preparation of division, district, upazila and city guide maps at different scales; demarcation of international boundary; processing, development and printing of aerial photography in Bangladesh. SoB also develops special maps for different Government Departments like geological survey, soil Survey etc.

SoB base maps and aerial images were used for the development of national land use maps of 1996 and 2004 by SRDI.

## 2.6 Bangladesh Space Research and Remote Sensing Organization

Bangladesh Space Research and Remote Sensing Organization (SPARRSO) is an autonomous organization under the Ministry of Defence (http://www.sparrso.gov.bd/). SPARRSO has been applying space and remote sensing technology, in the field of agriculture, forestry, fisheries, geology, cartography, water resources, land use, weather, environment, geography, oceanography, science, education, science based Knowledge and other related space research areas. It also performs research activities for developing this technology and its practical application and provides necessary information and disseminates research results to the Government and different relevant user agencies. SPARRSO was actively involved with Bangladesh Forest Department in preparing the national land cover map of 2005.

**Table 2:** Summary of the land cover maps developed for different areas in Bangladesh

| Project/title | Pub. year | Purpose | Institution (lead) | Institution (other) | Ground data | | Remote sensing | | | Number of classes | Estimation level* | List of the classes related to forest | Reference |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | Year(s) | Sampling method | Satellite and year(s) | Scale of interpretation | Classification method | | | | |
| National Land Zoning Project | Ongoing | To assign a land parcel to the best possible use, on the basis of its potentials and limitations | Ministry of Land | CEGIS | Various | | Various | | Supervised classification | Different for different upazila (sub-district) | National<br>Sub-district | | |
| FIGNSP | 2013 | To map forest coverage and related land cover in selected forest areas in Bangladesh | RIMS-FD | CEGIS | 2011-12 | Different spectral patterns of interest were marked on the maps by Visual interpretation. Each of these patterns was visited during the field survey. | IKONOS and RapidEye.<br>January 2011 to February 2012 | Various | Multi-resolution segmentation for image classification. Similar spectral classes grouped together, labelled with a land cover based on ground reference data. Expert knowledge based check to improve the accuracy of the declared information classes. | Three groups of land cover classes – 19, 20 and 17 | Sub-national.<br>Management unit | Natural Forest (Hill)<br>Natural Forest (Sal)<br>Natural Forest (Mangrove)<br>Natural Forest (Swamp)<br>Scattered Forest (Natural and Plantation)<br>Other Vegetation (Combination of Homestead type and Private & Public Plantation)<br>Bamboo Plantation<br>Plantation (Mangrove)<br>Rubber | (BFD, 2013) |

| Project/title | Pub. year | Purpose | Institution (lead) | Institution (other) | Ground data | | Remote sensing | | | Number of classes | Estimation level* | List of the classes related to forest | Reference |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | Year(s) | Sampling method | Satellite and year(s) | Scale of interpretation | Classification method | | | | |
| National Forest and Tree Resources Assessment 2005 - 2007 | 2007 | To conduct national wide assessment of forest resources and "tree resources outside forest". | FD | SPARSO | 2005 – 2006 | Sample sites were distributed systematically throughout the country at an interval of 15 minutes latitude and 10 minutes longitude. FAO's standard layout for Tracts, Plots and Subplots was adopted. | Landsat TM 2005 | | | 29 in the report | National | Hill Forest<br>Mangrove Forest<br>Mangrove Plantation<br>Rubber Plantation<br>Sal Forest<br>Shrubs<br>Hill Forest with Mixed Bamboo<br>Mango plantation<br>Mixed Bamboo<br>Shifting Cultivation<br>Swamp Forest<br>Tea Garden | (BFD, 2007) |
| Land use map 2004 | 2004 | | SRDI | | base map of 2001 of Survey of Bangladesh (SoB) forest cover map of 1994 from FD | | Landsat 2004 1994 1990 | | | 21 broad classes | | Mixed Evergreen & Deciduous Forest (including Reserved Forest)<br>Mixed thickets & Forest<br>Deciduous Forest(Sal)<br>Mangrove Forest<br>Planted Mangrove Forest | |
| Land use map 1996 | 1996 | | SRDI | | base map of 1989 of Survey of Bangladesh (SoB) | | Landsat 1984 and 1990 | | | 21 | | Upland forest<br>Mangrove forest | |

| Project/title | Pub. year | Purpose | Institution (lead) | Institution (other) | Ground data | | Remote sensing | | | Number of classes | Estimation level* | List of the classes related to forest | Reference |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | Year(s) | Sampling method | Satellite and year(s) | Scale of interpretation | Classification method | | | | |
| | | | | | Forest cover map of 1994 from FD | | | | | | | | |

* National, Sub-national, District, Management Unit, etc. level

# 3. Methodological outline

Land cover and forest monitoring activities are part of Bangladesh Forest Inventory (BFI) – a national process under the leadership of the Forest Department to assess and monitor national forest at regular time intervals. The process is a collaboration of numerous government, NGO, private and civil society partners. The outcome will be a government led BFI process allowing acquisition of robust and transparent estimates of trees and forest resources and changes well beyond the project cycle.

There are different parallel and sometimes overlapping activities to accomplish the goal of land cover and forest monitoring including collection of field data for the biophysical, socio-economic, biodiversity and wildlife parameters, digitization of forest boundary locations to strengthen land tenure issues, development of a harmonized national land cover map legend, designing a remote sensing based methodology for land cover map development and forest change detection, development of a web based platform for data sharing among national stakeholders, etc.

The following subsection provides an overview of the data and resources for the development of land cover and forest monitoring system. The rational of introducing LCML is explained in the next. After that the integration framework is presented and the steps under different components are elaborated in subsequent sections.

## 3.1 Available data and resources for the land cover and forest monitoring development

Land cover and forest monitoring at national level relies on a multitude of data of different spatiotemporal dimensions. These data sets are being used for the development of land cover and forest monitoring. **Table 3** summarizes the data and resources that are being used for land cover mapping and forest monitoring.

**Table 3:** Data and resources for the land cover mapping and forest monitoring

| Data/resources | Description/ Purpose |
|---|---|
| SPOT 6/7 images | - For the year 2015<br>- For land cover mapping |
| Landsat images | - For the period of 2000 to 2014<br>- To develop tree cover |
| National land cover database and satellite imageries of 2005-07 | - Forest monitoring, change detection |
| Land cover database and satellite imageries of forest areas of 2011-12 | - Forest monitoring, change detection |
| SRDI maps of 1996 and 2004 | - |
| Field data | - 800 points has been collected<br>- For legend development |
| Forest inventory data | - NFA 2005/7 |
| Software | - ERDAS Imagine 2015<br>- ArcGIS 10.3 |

## 3.2 On the use of Land Cover Meta Language

The definition of classes is one of the major issues with land cover databases. A study by the Food and Agriculture Organization of the United Nations/Global Land Cover Network (FAO/GLCN) identified more than 300 definitions of forest worldwide. The land cover classifications vary greatly from one country to another in terms of the definition of classes in addition to differences in spatial disaggregation and resolution. This variability creates challenges in the study of land cover dynamics, as the data available for different time slices are not sufficiently logically and spatially consistent for them to be compared scientifically. The heterogeneity of datasets limits their flexibility and efficiency in serving the multitude of potential applications.

With advancements in geospatial technology, the assessment and classification of land cover and land use has become a key management tool across a range of disciples allowing information of the state of flux of the earth's surface observed from time to time. Establishing consistency between the various classification systems increases management efficiency as standardized information can be used for multiple purposes. However, defining a unified classification system that both allow interoperability across discipline and space responding to the needs of the varying agencies is difficult due to their inherently differing priorities.

In response, the Global Land Cover Network (GLCN), a joint initiative between FAO, UNEP and IAO, have developed the Land Cover Classification System LCCS tool to assist countries to both harmonise existing land cover data and to establish a system where land cover classes are based on actual physical features present on the ground. In this way, the system favours an object oriented approach over one reliant on broad terminology that provides limited indication of the physical features it represents, and in doing so, the system presents a classification system that is transparent, comparable, standardized and replicable.

LCML/LCCS3 is an innovative object oriented meta-language that offers a new perspective for the semantic representation of land features. The characterization of land features results in a specific model that represent the objects, attributes and rules. In this respect, the method is ergonomic, dynamic and allows an adequate management of geographic data. The method is very different from traditional methods. However, the impact of the adoption of this methodology into a national system is much smoother and easier of what could be expected. It can be modulated in many different ways to fit different levels of expertise or willingness of the potential users to innovate their data production and management. The experience shows that the transition between two traditional legends is more complicated and difficult than the introduction to the LCML/LCCS method into a national system (A. Di Gregorio, 2016).

## 3.3 Integrated framework for land cover mapping and forest monitoring

The main objective of integration activities is to develop and implement a framework to integrate different activities being performed to accomplish the land cover and forest monitoring objectives. Figure 2 depicts the proposed integration framework. As shown in Figure 2, different activities related to land cover and forest monitoring are grouped under three broad categories: development of a national land cover legend; land cover map development, and tree and forest monitoring system. Required and ongoing activities within these broad components are numbered in parenthesis. It should be noted here that these numbers do not necessarily indicate sequential order, rather provide a logical connectivity between the activities. These activities are briefly described below. Further elaborations are provided in subsequent sections.

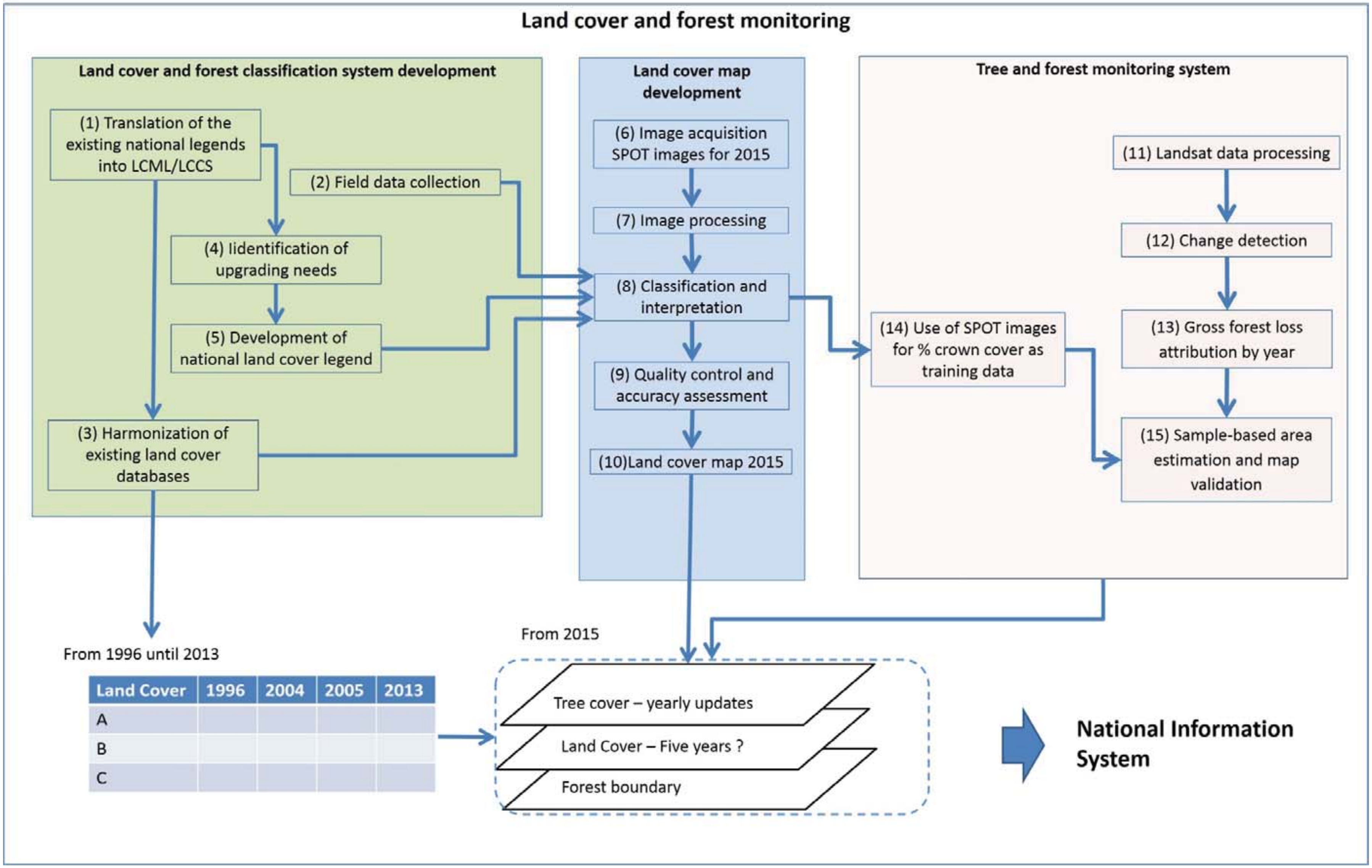
Several national institutions are collaborating for the development of a national land cover legend from different definitions and legends. Translation of existing land cover/use maps (i.e. the maps of 1996, 2004, 2005 and 2013) into LCCS legend (1) is a part of this process. These translation activities will result in identifying the gaps for upgrading (4). Together with field data collected for LCCS (2), the translated legends will feed into the development of a national legend (5).

SPOT images are being used for the development of land cover map of 2015 (6). After necessary pre-processing (7), segmentation method will be used to for classification (8) to generate spectral classes. These spectral classes will be assigned to appropriate land cover classes based on the developed national land cover legend (5) and LCCS field data (2). Another input for the classification and interpretation (8) will be the harmonized land cover databases (3) including satellite images collected for previous land cover maps. After quality control (intermediate and final) and accuracy assessment (9) final land cover map of 2015 will be developed (10).

FD-RIMS is developing annual forest gain-loss masks from 2000 to 2014, with the support from University of Maryland (UMD). The available archive of Landsat imagery from 2000 is processed (11) and employed for change detection (12) to obtain annual forest cover loss and gain masks (13). SPOT images can be used as training data for % crown cover (14).

One of the expected outputs of the harmonized existing land cover maps (3) is to ensure comparability of land cover classes among maps from different years (i.e. 1996, 2004, 2005, 2013) and to generate change matrix to investigate land cover changes over time. After the development of land cover map of 2015 and forest monitoring system, yearly updates of tree cover is anticipated. These yearly updates of forest masks, obtained from forest monitoring system, will be overlaid onto the harmonized forest classes of the different land cover maps to see to which land cover classes forest changes are taking place. The whole process is intended to contribute toward developing a national information system.

**Figure 2:** Integrated framework land cover and forest monitoring



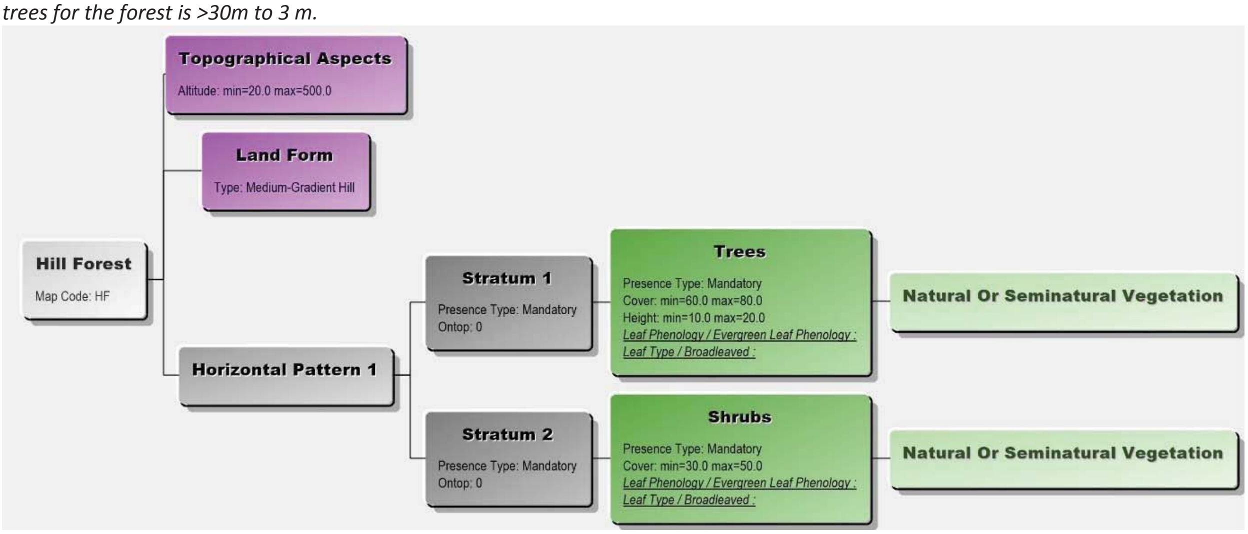
## 3.4 Land cover and forest classification system development

### Step 1: Translation of the existing national legends into LCML/LCCS

It consists of translating national legend classes, represented with a class name and a general text description, into the "object oriented" LCML/LCCS language. The land cover databases of 1996 and 2004 were prepared by SRDI and several data sources were used to prepare the datasets and maps. The database of NFA 2007 was prepared by Forest Department with the collaboration of SPARRSO. Classification systems for these databases are different and are represented with a class name and a general text description. LCCSv3 will be used to develop the definitions for the classification systems. These classes will be translated into the "object oriented" LCML/LCCS3 language. The LCCS schema will be an additional (more structured and systematic) description of the legend classes. The Figure 3 shows an example of the integration of the LCML/LCCS schema as part of the conventional description of a traditional class legend (in this case a class of the Natural Forest (Hill) legend has been considered).

**Figure 3** Example of a translated legend in LCCSv3

Natural forest (hill)*: the natural forest of sylhet forest division, chittagong forest divisions, cox's bazar forest divisions and areas under chittagong hill tracts are considered in the class. Forest of native species grows through natural regeneration or assisted regeneration is considered as natural forest. Open forests of 70 or 60% to 20 or 10% canopy coverage of natural forest is mostly covered by this class. The forest is semi evergreen type mostly and broadleaved often mixed with deciduous and ever green forest patches. Main height of the trees for the forest is >30m to 3 m.*




### Step 2: Field data collection

The field team will describe the objects of a given sample without assigning a class name. This approach simplifies the field survey avoiding the confusion between different class names and making the results from different teams comparable. A field data collection protocol is developed to allow non-experts, receiving basic training, to collect data and contribute to the built up of system. The field data collection procedure is described in the manual (BSGI, 2016). The management of field data and confirmation/upgrading of the legend classes are being done in collaboration with the stakeholders.

### Step 3: Harmonization of existing land cover databases

This activity involves harmonizing the datasets for different years in regards to definition, topology, coordinate system, projection etc. and check other inconsistencies. Source of the country boundary that was used to develop the databases in different years should be checked. This will ensure the use of harmonised databases for the development of change matrix to see the land cover changes.

**Step 4: Identification of upgrading needs**

Identification of potential needs for upgrading existing legends consists of identification of gaps or potential areas of improvement, both in term of class number, extension and rationalization of class meaning. The transition from a traditional legend to a LCML/LCCS3 approach allows evaluating the coherence, completeness and semantic content of a traditional legend.

In this context, the general structure of the legend would be partially modified ensuring continuity with previous mapping activities. However, the rationale for upgrading the legend is based on the LCML logic. The LCML structure can become a parallel configuration to improve the national LC classification system. The LCML approach would gradually become the reference structure for upgrading all classes. This would ensure smooth transition between past and future legends.

**Step 5: Development of a national land cover legend**

This step defines the legend for the country. The outputs of the activities under this step are:

- National legend produced and validated in LCCS3 software
- A textual description of each class in the legend
- LCCS diagram for each class
- Sample pictures for each class from
    - high resolution imagery (Google Earth or similar)
    - from the images used for the segmentation and
    - from the field.

The legend should describe all the possible features detectable from the images used in the work. A further refinement for less represented features may be applied during the generation of the land cover maps. An expert meeting was conducted to finalize the national reference system (Gregorio et al., 2016). Finally, a national consultation was implemented for building a consensus for the land cover classification system, adaptation and recommendations for its adoption by the various stakeholders.

## 3.5 Land cover map development

**Step 6: Image acquisition**

In this activity the criteria for choosing the images to be used in the land cover mapping are set and images are accessed. Minimum acceptable quality of images for cloud coverage is considered 10%. 6m multi-spectral ortho (level 3) SPOT 6/7 images with bit depth of 12 bits are acquired for the land cover mapping of 2015.

**Step 7: Image processing**

Mosaic of the scenes for the whole study area is recommended for the overlapping areas between the scenes to cut in order to remove clouds as much as possible but to not apply any smoothing to these areas. Other open sources of satellite data (e.g Sentinel 1 and 2) can be used for cloud masking and gap filling. Image enhancement can be considered for visual purpose only, not for image analysis.

Image processing should be conducted by one institution.

**Step 8: Classification and interpretation**

The segmentation can be applied to a single period or to multiple periods. It is recommended to use a segmentation to a single period. The segmentation process may be applied to more than 3 bands, but it is recommended to use the same bands that will be used in the interpretation. 432 band composition (NIR, R, G) has been recommended, but some tests applying the segmentation to other band composition should be evaluated. The resulting shapefile should be simplified to reduce its size after segmentation. Definition of parameters used for segmentation should be well documented (exported in the resulting image).

Interpretation of the objects (polygons) detected during the segmentation process normally requires to split the result of segmentation in various tiles to be worked by many photo-interpreters. An appropriate combination of hierarchical, semi-automatic and manual assignment of classes should be employed. Training points on the interpretation can be used for automatic supervised classification. LCCS3 basic coder will be used for interpretation.

### Step 9: Quality control and accuracy assessment

An intermediate evaluation of the interpretation should be conducted to avoid producing a map with poor accuracy and to amend the interpretation process. The quality check can be conducted in the country with ground truth data (e.g. roads transects, simple surveys) or with pseudo-truth data (available images or aerial photos). If the intermediate result does not attain a minimum standard the scenes need to be re-interpreted.

Before the accuracy assessment, a final quality control is required. This should address logical inconsistencies. It can also involve field validation for specific classes. If multiple tiles are used, after mosaicking, the borders have to be checked to remove obvious inconsistency on classified polygons**.** During this phase, the final map is dissolved, a check on topology and table of attributes is conducted to avoid inconsistencies.

The accuracy assessment is important information to attach to a land cover map. It is normally conducted by a thid-party and can use ground truth data, pseudo truth data or a combination of both. Definition of the sampling strategy and design of the sampling should be developed. A survey will be conducted according to the decided strategy. Finally based on the analysis of the data and production of confusion matrix, accuracy parameters for each class will be generated.

There are several issues decisions on which are to be taken as presented in Table 4.

**Table 4:** Decisions to be taken

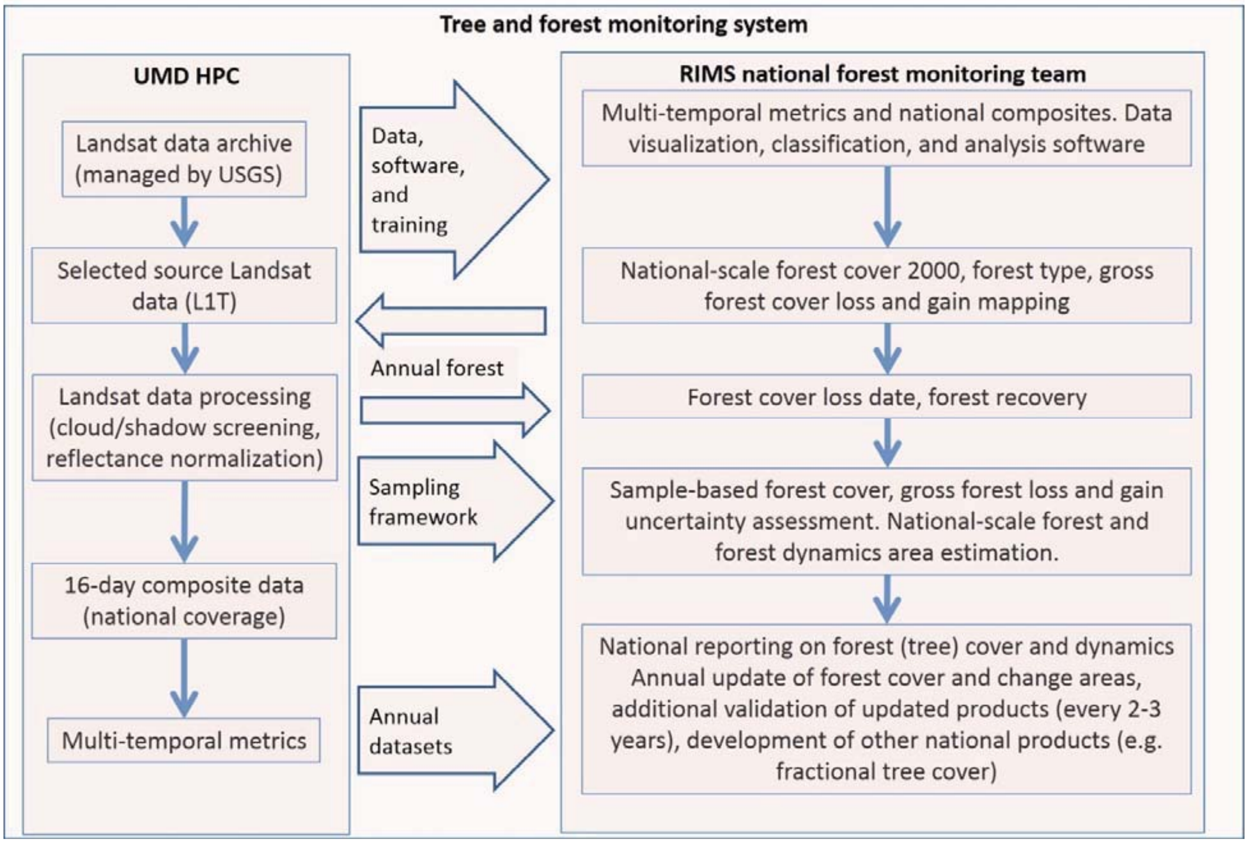
| Issues | Description |
|---|---|
| Image processing | - What processing works are needed?<br>- One institution should do the processing<br>- Time frame |
| Segmentation | - What should be the approach? Mosaic of the whole area or scene by scene?<br>- If scene by scene issue of edge matching. Solution may be to create 8-10 blocks for the country. |
| | - Segmentation method and parameters |
| | - Band composition (fixed or flexible), possibility to include radar |
| Minimum mapping unit (MMU) | - Depends on output map scale, etc. MMU may be in the range between 0.1 and 1 ha (Landsat resolution). |
| Interpretation | - Automatic classification method<br>- Use of field data |
| | - How many people for interpretation<br>- Estimated time frame for each interpreter to interpret |
| Quality control | - Sampling strategy<br>- Automatic quality control<br>- Threshold for re-interpretation |
| Accuracy assessment | - Sampling strategy |
| Integration | - Integration of land cover maps of delta region and rest of the country – CEGIS and FD-RIMS will work jointly |

| Issues | Description |
|---|---|
| | How and where to use radar data?<br>- Necessity => test on small area<br>- Under- or over-sample (e.g. 6m vs. 10m)<br>- Tree cover |

## 3.6 Tree and forest monitoring system

FD-RIMS, with the support of University of Maryland, is developing yearly update of the Tree Cover and Tree Cover Change product. The overview of the workflow is shown in Figure 4. Broad steps are described below.

**Figure 4:** Overview of workflow for tree and forest monitoring (UMD-GLAD methodology)




*Source: Reproduced from Potapov (2015)*

### Step 11: Landsat data processing

Landsat data from year 2000 to 2014 are processed and composited by UMD to create a nation-wide set of multi-temporal spectral metrics. The Landsat data are transformed from L1T imagery to multi-temporal metrics (Hansen et al., 2013b). The digital numbers of the reflective bands are converted to top-of-atmosphere reflectance and the thermal band to brightness temperature using standard protocol (Chander G, 2009). A set of quality assessment models is then applied to each pixel of an image, resulting in a quality data layer that identified pixels affected by clouds, haze, and cloud shadows. A radiometric normalization is applied to all images to reduce reflectance variations between image dates due to atmospheric conditions and surface anisotropy. A low spatial resolution (250 m) cloud-free surface reflectance product from MODIS is employed as a normalization target.

Metrics are extracted at a per-pixel level from all cloud and cloud shadow-free observations from 2000 to 2014. The metrics set included start/end image composites, rank-based metrics, and trend analysis metrics. The first and last single cloud-free observations are selected as the cloud-free observations closest to the end

### Step 12: Change detection

Forest cover loss is defined as any disturbance event leading to complete or nearly complete removal of tree cover within a Landsat pixel. The spectral metrics are used as independent variables for wall-to-wall gross forest cover loss detection for the 2000–2014 time interval. This task is performed using a supervised decision tree classification algorithm (Breiman, 1984). Sample-based estimates provided total gross forest cover loss area, while the wall-to-wall Landsat-scale map is used to disaggregate this area by change date, change factor, and by region. A group of image analysts at FD-RIMS is performing visual interpretation of the training sites, mapping areas of stable forest cover and gross forest cover loss from 2000 to 2014. Analysts are using a number of additional datasets, including freely available high-resolution images from GoogleEarth™ as reference materials to aid interpretation. All events resulting in forest cover loss (permanent or temporal) at the 30 m pixel scale, are mapped together as the forest cover loss class.

### Step 13: Gross forest loss attribution by year

To disaggregate change areas by forest clearing date an analysis of annual NDVI profiles is being employed. For each year the minimal annual NDVI value is collected per pixel. For all change pixels, inter-annual minimal NDVI difference is analyzed, and the year representing the highest drop in NDVI is selected as the change date.

### Step 14: Use of SPOT images for % crown cover as training data

The use of SPOT derived tree/non-tree classification as training data for a Landsat based canopy cover (Figure 5) percentage gave very promising initial results and will be further explored as an another area of integration.

A second opportunity for the integration is the use of SAR data in the tree and forest monitoring system. Especially the integration of ALOS K&C data is promising in this regard, since L-Band systems are known to be most sensitive to structural attributes which stands in relation to the % crown cover. But also Sentinel-1 is assumed to add information and improves the estimates. Hence, the relation of the percentage tree cover can be established between the multi-data stack of Landsat, ALOS and Sentinel-1.

The ALOS K&C data has already been downloaded and processed and is available from the FAO-BGD office.

**Figure 5:** Use of spot images for Landsat based canopy cover


SPOT tree/non-tree

Landsat canopy cover

### Step 15: Sample-based area estimation and map validation

The sample-based analysis goals are to estimate area of gross forest cover loss, primary forest extent, and map accuracy. A two-stage cluster sampling design is implemented with the first stage being a stratified random sample of clusters (4 strata) and the second stage being a simple random sample of pixels within clusters.

### Step 16: Change attribution

The forest mask of 2000 (developed by FD-RIMS using UMD-GLAD methodology) will be used reference based on which forest loss will be tracked as deforestation during the period of interest. All changes due to deforestation will be identified from the 2000 forest map. For the monitoring period this map will represent the forest benchmark map. To identify forest change the annual gain and loss forest masks from 2000 to 2014 will be overlaid with the harmonized national land cover maps of 2004, 2005-07, 2013 and 2015. This will reveal the land cover classes to which forest land are converted.

### Step 17: Development of geo-portal

Geo-portals have been established in a number of countries to support forest monitoring objectives. A geo-portal is being established to support forest monitoring objectives. This web based platform will act as a repository for spatial data and allow interactive visualization of field and remote sensing data related to forest and biomass dynamics, management activities and other project management related information. A custom standard will be applied to provide basic statistics. Advanced reporting can be provided according to country specific requirements.

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