

Toward Efficient Land Cover Mapping: An Overview of the National Land Representation System and Land Cover Map 2015 of Bangladesh

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Abstract—In response to prevailing classification inconsistency between land cover maps, developed by different organizations in different times at different scales, an object-based National Land Representation System (NLRS) for Bangladesh has been developed. The process, which began in 2013 and was completed in 2016, brought together several national organizations and involved an extensive process of consultation, data collection, translation, and analysis of existing land cover/use classification systems. The process focused on the interpretation of three legends from historic national land cover/use maps. Field inventory data were collected from over 1000 sites across the country to assist the process of land characterization and the development of a dynamic and representative overview of land cover and land use in Bangladesh. The system has been applied to the development of a wall-to-wall national land cover map for the year 2015. In this article, the methodological process and results of NLRS formulation and land cover map 2015 are presented. We also provide examples of how this interoperable system and the land cover dataset are being used for variety of applications including national forest resources assessment, estimation of REDD+ activity data, integration of biophysical and socioeconomic information, and semantic similarity assessment.

Index Terms—Consistency, harmonization, interoperability, land cover ontology, standardization.

I. INTRODUCTION

NATURAL resources management decisions are highly dependent on data quality which is in turn influenced by the

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classification system used to monitor the evolution of natural and land resources and their services [1], [2]. The increased use of earth observation data combined with geospatial techniques has resulted in an expansion in the production of land cover datasets. This development, enhancing the value of land cover information and at the same time enlarging the base of potential users, poses new challenges for its harmonization and consistent use [3] since compatibility and comparability are often lacking between these land cover products. Land cover changes assessed by comparing inconsistent maps can produce results that reflect changes from the inconsistencies and not real changes. An example from Great Britain demonstrated that up to 59% of the observed land cover changes were caused by inconsistencies between the respective maps [4].

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 [5]–[9]. However, discrepancies have been shown both between these different maps [10] and between these maps and the national estimates [9]. Considering such inconsistencies, a clear challenge is thus to effectively combine different top-down and bottom-up approaches, a recommendation made by the United Nations Framework on Climate Change Convention (UNFCCC) in the context of reducing emissions from deforestation and forest degradation (REDD+) [11]. 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) to label the various identified land cover classes is recognized to be a promising option to ensure homogeneity between different country-specific legends and maps [12].

In Bangladesh, various agencies develop land cover maps for a range of purposes, by making use of remote sensing and ancillary data [13]. However, inherent differences in organizational mandates as well as dissimilarities in methodologies, boundaries, definitions, classification systems, and capacities often limit the utility and comparability of land cover maps across time, space, and organizations. In some cases, classification systems vary within the same organization. For instance, the wall-to-wall land cover map and the national forest inventory, conducted under the National Forest and Tree Resource Assessment 2005–2007 [14], estimated different forest areas in Bangladesh. In this case, the final area estimates were generated using a combination of findings from both. Since different classification systems were used, expert judgment was considered to identify the best estimates of forest classes. Such integration efforts, used to harmonize the information, result in a loss of information (e.g., by using fewer aggregated higher level classes) and more importantly reduce the utility of land cover maps as a source of spatially explicit information limiting the use of different land cover maps and their integration into one system.

A standardized classification system for the entire country is, hence, valuable for producing efficient and consistent land cover information that are interoperable and potentially harmonized to satisfy the growing requirements of a wider end-user community. In this article, we provide the methodology and results of the National Land Representation System (NLRS) development process in Bangladesh and its application in developing the national land cover dataset for the year 2015. We note that

this is the first ever initiative of its kind implemented at a national scale. We also show how the system and the land cover dataset have many practical utilities for spatiotemporal analysis not previously possible with static maps built on conventional text-based classification.

II. STANDARDIZATION OF LAND COVER

Consistent definition of land cover classes is one of the major issues when mapping land features. However, 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 [15]. While this variability is perfectly justifiable when considering a local context and a specific purpose, it creates challenges in the study of land cover dynamics, as the data available for different time periods may not be logically and spatially consistent in the context of scientific comparison. This heterogeneity between datasets limits the flexibility, utility, and efficiency of these maps to serve the multitude of potential applications.

In response, the Global Land Cover Network (GLCN), a joint initiative between FAO, UNEP, and IAO, has developed the Land Cover Meta Language (LCML) to assist countries to both harmonize land cover data and to establish a system where land cover classes are based on actual physical features present on the ground. LCML is an ISO (International Organization for Standardization) standard (ISO 19144-2) which defines an innovative object-oriented meta-language allowing flexibility in the description of land features [3]. LCML emphasizes spatial distribution patterns and overall appearance of real-life vegetation/nonvegetation elements over traditional, semantic-based classification. It favors 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 language that is transparent, comparable, standardized, and replicable, rather than a predetermined fixed number of classes [3], [16].

III. DEVELOPMENT OF NATIONAL LAND REPRESENTATION SYSTEM OF BANGLADESH

The NLRS of Bangladesh [17] is a result of several processes of data collection, translation, gap identification, and analysis of existing land cover/use mapping processes. This process was started in 2013 and was finalized in 2016 [13], [16], [18]–[26]. The legends of three existing national land cover/use maps were collected, documented, and translated using the Land Cover Classification System (LCCS v3)—an implementation tool of LCML [16]. This step identified the gaps in existing legends and assisted the interpretation of land feature classes considering the objectives of the institutions responsible for land cover map development. In parallel, field data were collected, using Open Foris Collect [21], from 1144 locations across the country in order to characterize the national classes of the NLRS [19].

In March 2016, a national workshop for the development of the NLRS was organized. In this workshop, with the contribution of experts from different national organizations, a draft national land representation system for land cover/use mapping was

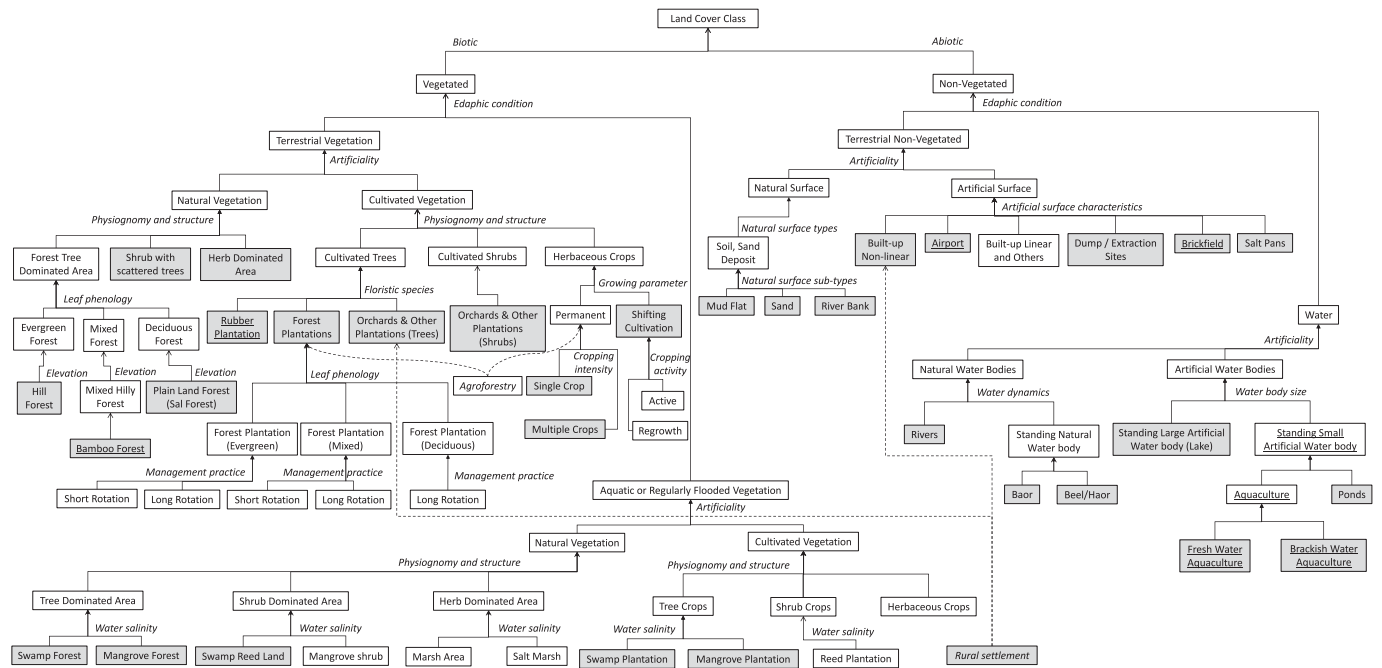


Fig. 1. Schematic overview of the relationship between classes of the NLRs and land cover map 2015 legend. The NLRs classes are in rectangular box. Legend classes are in gray box. Legend classes extended from NLRs are underlined. Mixed classes are in italic.

developed. The flexibility and comprehensiveness of the system to accommodate and integrate all possible national classes were tested and recognized during a national consultation (held right after the workshop) with stakeholders from 15 national organizations [25].

IV. DEVELOPMENT OF NATIONAL LAND COVER MAP 2015

The national land cover map 2015 is the first map of its kind in Bangladesh following the LCML approach. The methodology used for the mapping activities [27] is presented in the following sections.

A. Derivation of Land Cover Legend From the National Land Representation System

The legend classes for the national land cover map 2015 were derived from the NLRs based on the distinction of classes from satellite image interpretation, availability of ancillary data, and expert knowledge [28]. From the NLRs, the initial classes for land cover map 2015 were derived during a national workshop with experts from different organizations working in relevant fields [29]. These initial classes were further refined during map development process to develop the final legend. Some of the classes were extended from the NLRs (e.g., bamboo forest, rubber plantation, etc.), while some other classes were merged (e.g., short and long rotation plantation into forest plantation) (see Fig. 1) when distinctions among these classes were not discernable from the images.

B. Image Acquisition and Preprocessing

Multispectral ortho (Level 3) SPOT6/7 images of 6-m spatial resolution with maximum 10% cloud coverage were

used for the whole country. The acquisition dates of SPOT 6/7 images were within January and October–December, 2015. The images have the spectral bands of blue (0.455–0.525 μm), green (0.530–0.590 μm), red (0.625–0.695 μm), and near-infrared (0.760–0.890 μm). To delineate land cover classes with temporal variability (e.g., single and multiple crops), Landsat 8 and Sentinel 2 images of March–April and September–November for the same year were used.

Land cover mapping was done separately for each of the 64 districts of the country. Images encompassing a particular district were first identified for mosaicking. These images were then ranked (in terms of cloud coverage and contrast) and the order of the scenes was maintained in mosaicking to minimize cloud body coverage in the overlapping areas.

C. Segmentation

Object-based image analysis (OBIA) approach was adopted to create image objects defined by spectral, spatial, contextual, and hierarchical properties. In particular, multiresolution segmentation algorithm [30] was used to develop image objects using the bands green, red, and near-infrared (NIR) with equal weights as input layers. The choice of the scale parameter, the most critical value that influences the detail of the segmentation (i.e., how many polygons are generated), was iteratively tested to identify homogeneous polygons. The segmented files were then exported with the attributes, including, mean variance of each band, brightness, Normalized Difference Vegetation Index (NDVI), and length-to-width ratio. These files were further simplified to reduce vertex density and consequently file size.

D. Classification and Interpretation

The image segments developed were used as the basic unit of classification. Meaningful image segments [31] were directly assigned with land cover code. Not-qualified image segments were manually edited to correspond well to geo-objects in geometry before assigning appropriate land cover code. These were the most consuming task of the whole production chain and required the largest number of staff. All the photo-interpreters were trained to have a clear understanding of the land cover legend based on LCML approach and of all the conditions and criteria to detect each class. Photo-keys for each land cover classes with various satellite imageries were prepared to support the interpretation.

The districts were interpreted by assigning the code in a specific order of major land cover classes rather than assigning the code by sequential polygons. The most represented and discernible classes (e.g., water bodies, rural settlements, artificial surface, etc.) were interpreted first, followed by the challenging ones (e.g., forest and cropland classes). Seasonal variations in land and water features are very common in Bangladesh. Landsat 8 and Sentinel 2 images from different seasons were taken into consideration in interpreting areas having a seasonal variation (especially agricultural classes).

E. Quality Checking

Quality checking was an integral part of the whole production chain and was completed using multiple approaches [32]. Spatial topology was checked to verify that there were no overlapping polygons and no gaps exist between polygons. Attribute check was performed to ensure that assigned land cover codes are consistent with the national land cover legend codes. It was also verified that no consistency errors were present (e.g., mangroves in elevated areas). Classes, which were unusually present or absent in a particular district, were noted and rechecked by expert judgment. Inconsistencies, that were not possible to be addressed by expert opinion, were checked through field visits of those particular areas and the land cover data were revised accordingly.

F. Accuracy Assessment

The accuracy assessment analysis was designed using a pseudo-ground truth validation technique, with a stratified random sampling by district and by land cover class. The districts were categorized into three groups (i.e., small, medium, and large) based on district size. Numbers of sample units for small, medium, and large district were assigned as 150, 200, and 250, respectively. The number of sample units for each land cover within a district was determined by the relative occurrence (in terms of area) of the land cover in the district. Minimum number of sample units was set to 50 at national level.

For the collection of reference data, 100 by 100 m homogeneous spatial assessment unit was used. Homogeneous unit is considered as one which is assigned fully to only one class. Sample units were then randomly allocated with a routine developed in R and visually classified in the accuracy assessment

workshop [32], by GIS and land cover experts from different national organizations according to the historical Google Earth imagery of 2015. During the accuracy assessment workshop (held in February 2017), historical imagery of Google Earth for 2015 covered whole Bangladesh with images mostly between 2014 and 2016 and with resolution higher than SPOT imagery used for the mapping activities. The reference class was defined as the best available determination of the ground condition at the sample units in 2015 with support from expert judgment and local knowledge. The reference class label is assumed to be correct considering the fact that that reference classification error often occurs and may have implications for analysis of accuracy of land cover by remote sensing [33]. It is to be noted here that visual discrimination between single crop and multiple crops was not possible from Google Earth imagery. These classes were grouped into higher level class of the NLRS for reference data collection.

V. RESULTS

A. National Land Representation System

The NLRS aims to address the entire information domain and subdivide it according to a set of rules to produce a set of classes (and subclasses). It is divided into distinct levels for complete understanding of all possible land features in Bangladesh (see Fig. 1). The whole logic of the system is based on an object-oriented approach. Each of the categories populating it is constructed according to the ISO standard LCML. The system works by making available a set of basic standard LCML object/element (for instance, trees, shrubs, buildings, etc.) that are organized in strata and enriched with different types of attributes. These LCML elements act as standardized building blocks and are combined to describe the more complex semantics of each land cover class. For each of the classes instantiated in the system, an LCCS instantiation model exists in graphical (an example of graphical format is given in Fig. 2) and XML format, and is stored in the system digital registry. This facilitates the representation of the real-world features in an easier and more accurate way by making objective understanding of class ontology and also allows efficient utilization in an advanced GIS modeling environment. Detailed elaboration of the NLRS classes and their formation has been documented in GoB [17].

An overview of the system components and their functional relationship is presented in Fig. 3. As shown in Fig. 3, LCML register of characteristics supports a list of possible attributes for describing/expanding class information. LCML syntax gives the conceptual base for the built-up of the system classes. These classes are arranged in different levels to clearly instantiate the class inheritance forming the “Overall System Architecture.” Finally, the whole system supports any type of legend that can be tailored to specific needs being at the same time fully coherent with the system.

B. National Land Cover Map 2015

A wall-to-wall national land cover map and area statistics were produced for different levels of classification (Table I

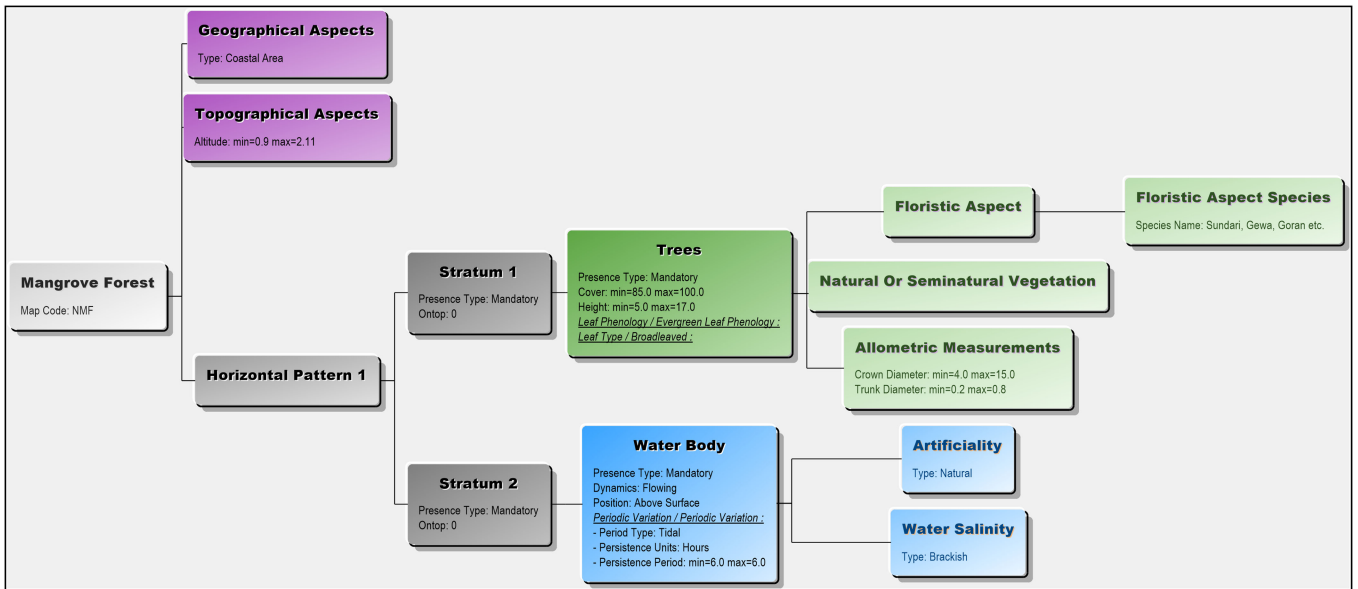


Fig. 2. Model representation of graphical format of the class “Mangrove Forest”—described as a combination of two mandatory stratum of trees and water body. These LCML objects/elements (i.e., trees and water body) are further enriched with respective attributes—cover percentage, height, leaf phenology, etc. for trees and dynamics, periodic variation, water salinity, etc. for water body.

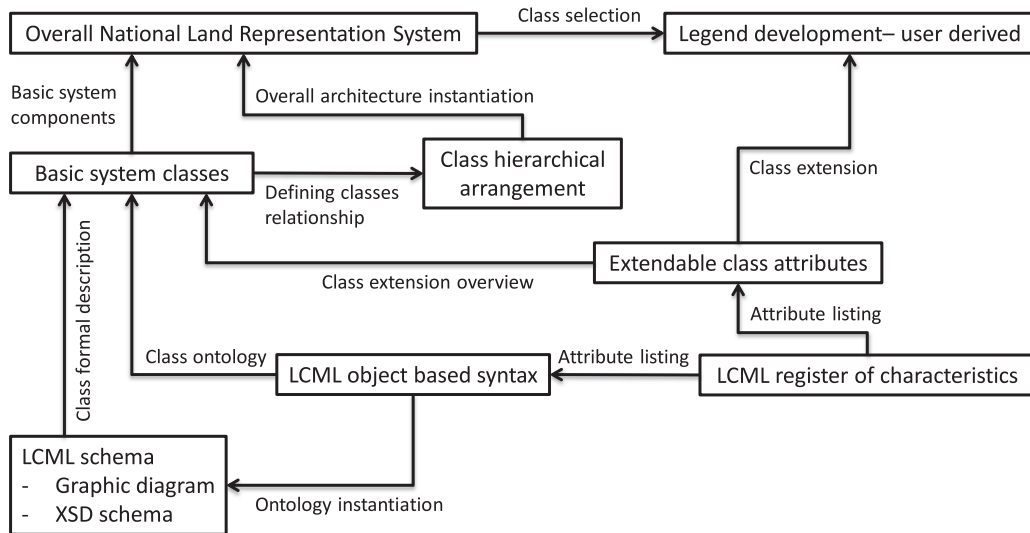


Fig. 3. Overview of system components and their functional relationship.

and Fig. 4). The most commonly used measures of accuracy (i.e., overall accuracy, user’s accuracy, and producer’s accuracy) are estimated following the approach suggested in [34] and presented in Table II. The overall accuracy was estimated at 89%. User’s accuracy ranged from 20% to 99% while weighted producer’s accuracy ranged from 13% to 100%.

The results show that permanent crop (an aggregated class of single crop and multiple crops) is the single dominant land cover occupying about 71 708 km² (nearly half of the country). Rural settlement and rivers and khals (channel) are other prominent land covers extending about 31 245 and 12 536 km² (21% and 8% of the country), respectively. Of the forest, hill forest

(6839 km²) and mangrove forest (4022 km²) are the dominant ones occupying about 7.4% of the country.

C. Ongoing/Potential Applications

1) *Assessment of Indicators:* Land cover map 2015 can be directly/indirectly used for assessment of seven indicators under three sustainable development goals (SDGs) as follows:

- 1) proportion of agricultural area under productive and sustainable agriculture (Indicator 2.4.1);
- 2) proportion of bodies of water with good ambient water quality (Indicator 6.3.2);

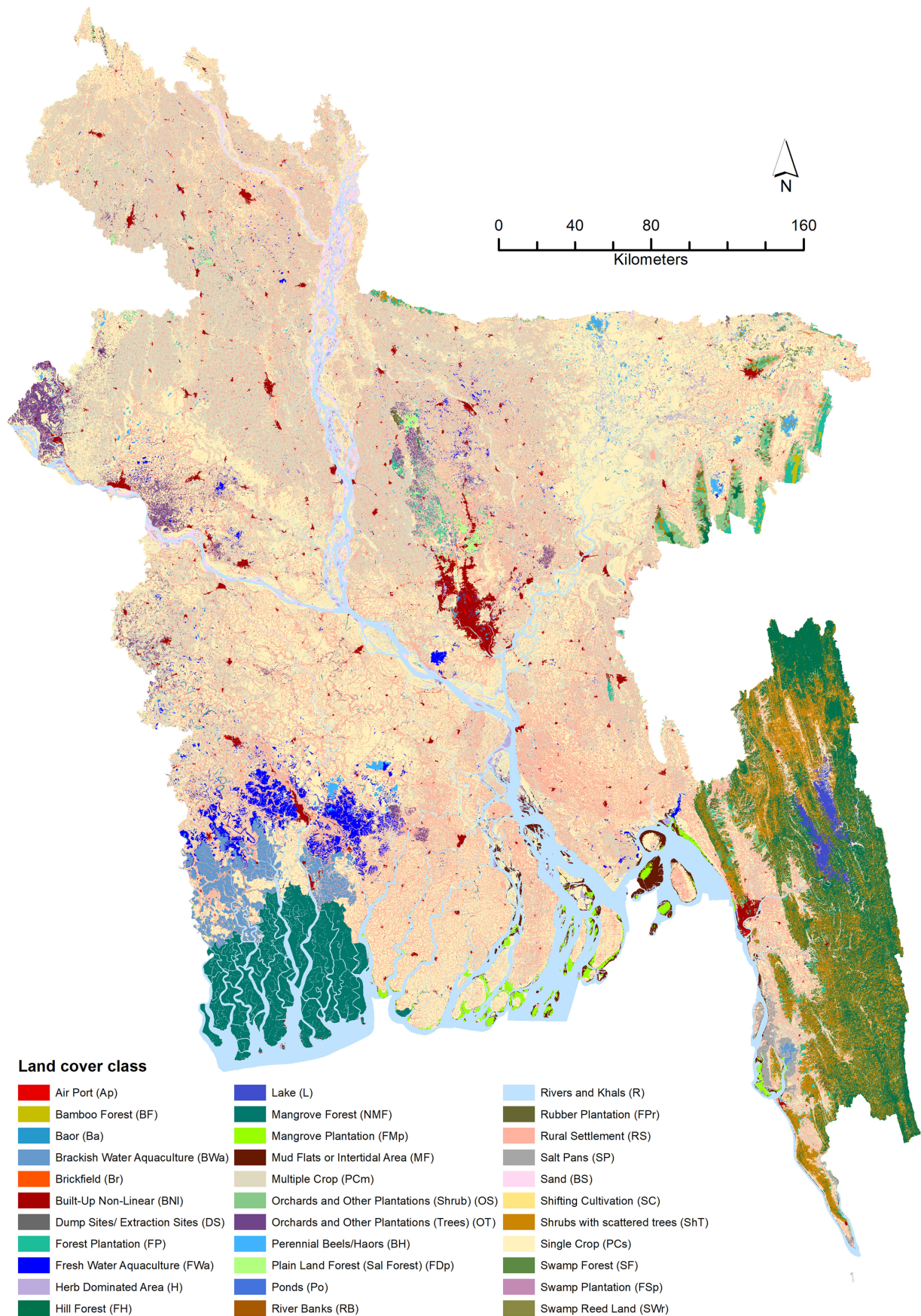


Fig. 4. Land cover map 2015 of Bangladesh.

TABLE I
LAND COVER AREA STATISTICS AT DIFFERENT LEVELS OF CLASSIFICATION

Land cover at different levels						Map area		
Level 1	Level 2	Level 3	Level 4	Level 5	Level 6	Km ²	%	
Vegetated area	Terrestrial	Natural	Tree dominated area	Evergreen forest	Hill forest	6,839	4.634	
				Mixed forest	Bamboo forest	57	0.039	
				Deciduous forest	Plain land forest (Sal forest)	189	0.128	
			Shrub dominated area	Shrubs with scattered trees	6,145	4.164		
			Herb dominated area	Herb dominated area	654	0.443		
		Cultivated	Cultivated trees	Rubber plantation	Rubber plantation	237	0.160	
				Forest plantation	Forest plantation	793	0.537	
				Orchards and other plantation	Orchards and other plantations	1,807	1.224	
				Cultivated Shrub	Orchards and other plantation	703	0.476	
				Herbaceous crops	Permanent crop	Single crop	43,485	29.467
					Multiple crop	28,223	19.125	
					Shifting cultivation	343	0.232	
	Aquatic or Regularly flooded	Natural	Tree dominated area	Swamp forest	Swamp forest	1	0.001	
				Mangrove forest	Mangrove forest	4,022	2.725	
				Shrub dominated area	Swamp reed land	134	0.091	
			Cultivated	Tree crop	Mangrove plantation	Mangrove plantation	551	0.373
					Swamp plantation	Swamp plantation	6	0.004
	Rural settlement	Rural settlement	Rural settlement	Rural settlement	Rural settlement	Rural settlement	31,245	21.173
	Non-vegetated area	Terrestrial	Natural	Soil, sand deposit	Mud flats or intertidal area	Mud flats or intertidal area	763	0.517
					Sand	Sand	1,513	1.025
River banks					River banks	8	0.005	
Artificial				Built-up non-linear	Built-up non-linear	Built-up non-linear	1,792	1.214
					Airport	Airport	25	0.017
Water			Natural	Rivers and khals	Rivers and khals	Rivers and khals	12,536	8.495
					Baor	Baor	185	0.125
					Perennial beels/haors	Perennial beels/haors	576	0.391
Artificial			Standing large artificial waterbody	Lake	Lake	533	0.361	
				Fresh water aquaculture	Fresh water aquaculture	1,903	1.290	
		Brackish water aquaculture		Brackish water aquaculture	1,570	1.064		
		Ponds		Ponds	106	0.072		
Total						147,570	100	

- 3) change in the extent of water-related ecosystems over time (Indicator 6.6.1);
- 4) forest area as a proportion of total land area (Indicator 15.1.1);
- 5) progress toward sustainable forest management (Indicator 15.2.1);
- 6) proportion of land that is degraded over total land area (Indicator 15.3.1);
- 7) mountain green cover index (Indicator 15.4.2).

Indicator 15.1.1 can be directly assessed using the land cover dataset. For the assessment of remaining indicators, land cover information can be used as baseline in combination with other relevant information.

Apart from the assessment of SDGs indicators, the land cover 2015 is being used in assessing several indicators [35] relating to the 7th Five Year Plan (7FYP) [36] (the country's main planning framework for development) and the Country Investment Plan on Environment, Forestry and Climate Change (CIP EFCC) of Bangladesh [37]. The land cover 2015 is being used as a bridge to integrate the biophysical data collected through plot measurements [38] with socioeconomic data collected through household questionnaire survey [39] for the Bangladesh Forest Inventory (BFI). Relevant biophysical and socioeconomic information are mapped to the land cover classes that allow the assessment of indicators on biodiversity and conservation; disturbance, forest degradation, and resilience; economics and livelihood; forest area and characteristics; measuring progress toward sustainable forest management (SFM); and forest

productivity and protective functions at national and subnational levels for different reporting purposes [35].

2) *Estimation of REDD+ Activity Data*: The land cover 2015 is used in developing spatially explicit REDD+ activity data [40]. To calculate the land cover change areas (i.e., forest remaining as forest, other land converted to forest, and forest converted to other land), a land cover map for the year 2000 (using Landsat images) was developed using the NLRS based classification system. Although the final categories of the legends of land cover maps of 2000 and 2015 were different, use of NLRS ensured the consistency between the two maps and allowed harmonization of the legends to overlay the maps for developing land cover change map. The resultant change map was then integrated with the 2000–2014 tree cover data [41]. For each polygon of the land cover change map, change in percentage tree cover was calculated. This integrated layer of land cover and tree cover change was then used to define REDD+ activities based on the definition adopted in GoB [40].

3) *Operationalization of Semantic Interoperability*: Bangladesh Forest Information System (BFIS) geoportal is being developed as a national platform to integrate and access geospatial information for forestry in Bangladesh (<http://geoportal.bforest.gov.bd/>). Semantic analysis and interpretation of LCML-based land cover classes is one of the core parts of BFIS geoportal. This GeoNode-based geoportal employs a “mixed” database architecture, pairing a GeoServer data source for managing geospatial data with a document oriented database that handles the LCML basic elements and attributes. Hosted in

TABLE II
ACCURACY ASSESSMENT RESULTS

Class	Sample number	Number correct	Producer's accuracy (weighted)	User's accuracy	Adjusted area (km ²)	Standard error (km ²)	Overall accuracy
Air port	50	33	1.00	0.66	17	2	0.89
Bamboo forest	50	35	0.64	0.70	62	16	
Baor	50	31	0.61	0.62	186	28	
Brackish water aquaculture	107	76	0.78	0.71	1434	88	
Brickfield	60	51	0.84	0.85	212	19	
Built-up non-linear	367	286	0.50	0.78	2810	144	
Dump sites/ Extraction sites	50	31	0.48	0.62	57	14	
Forest plantation	70	39	0.65	0.56	681	76	
Fresh water aquaculture	191	85	0.60	0.45	1422	104	
Herb dominated area	84	34	0.37	0.40	708	89	
Hill forest	588	522	0.68	0.89	8942	223	
Lake	50	44	0.87	0.88	537	34	
Mangrove forest	305	302	0.95	0.99	4191	45	
Mangrove plantation	52	29	1.00	0.56	307	38	
Mud flats or intertidal area	68	50	0.58	0.74	971	70	
Orchards and other plantations (Shrub)	90	62	0.82	0.69	591	57	
Orchards and other plantations (Trees)	133	98	0.47	0.74	2821	158	
Perennial beels/haors	86	40	0.28	0.47	956	85	
Permanent crop	7410	7152	0.95	0.97	72648	240	
Plain land forest (Sal forest)	50	32	0.69	0.64	176	27	
Ponds	50	29	0.19	0.58	315	54	
River banks	50	34	0.13	0.68	41	17	
Rivers and khals	1526	1476	0.95	0.97	12698	91	
Rubber plantation	50	45	0.57	0.90	374	58	
Rural settlement	2186	1921	0.96	0.88	28572	244	
Salt pans	50	39	0.79	0.78	370	38	
Sand	231	174	0.76	0.75	1502	71	
Shifting cultivation	50	10	0.23	0.20	292	77	
Shrubs with scattered trees	232	91	0.68	0.39	3548	221	
Swamp forest	50	49	0.32	0.98	4	3	
Swamp plantation	50	24	1.00	0.48	3	0	
Swamp reed land	50	37	0.82	0.74	122	15	
Total	14486	12961			147570		

this geoportal, a novel object-based methodology [42] is being operationalized to make an automatic similarity assessment between LCML-derived classes present in different databases. The approach considers correspondence (i.e., likeness of different LCML elements) and extensiveness (i.e., number of different LCML elements). For properties and characteristics represented by a range of numerical values, the system quantifies the overlap of the two values. The users can define a set of semantic “filters” or legend classes, using the LCML objects. By applying this reclassification legend, the LCML class associated to each geographical object can be compared with the user-defined legend class, and each geographical object can be reclassified to the most similar new class (user-defined or imported class). In brief, the system can semantically exploit the granular information present in LCML classes in order to assess similarities between them and optionally reaggregate classes and legends through user-defined criteria.

VI. DISCUSSION

Broad ranges of user's and producer's accuracies across the land cover were observed. Accuracies were lower particularly in south-eastern hill region of the country mainly because of the difficulty in separating shrub from other vegetation areas. Shrub area was almost exclusively located in the five south-eastern hill districts and was found to be challenging to distinguish

from forest area using single-dated medium-resolution satellite images like SPOT 6/7. Lack of ground-based information due to inaccessibility was another major issue in separating shrub from forest in this region. In a similar situation, use of very high-resolution and multi-dated satellite data is recognized to result better accuracy [43].

The classes of NLRs are essentially “meta classes” and can be further extended according to the needs of specific applications. The overall system is not to be considered as a rigid hierarchical system; rather the class hierarchy in the system (presented in Fig. 1) reflects the inheritance of subclasses to upper level class. This offers more flexibility in that the user is free to use the system classes and at the same time can expand/aggregate the system classes as necessary. A practical example of such flexibility is the development of consistent legends for land cover maps of 2000 and 2015.

While the responsibility to monitor and assess the status of natural resources is being given to a multitude of institutions, the collaboration between them is often limited by the way natural resources are being represented for different interests. Despite the efforts in standardization and harmonization, there is only limited compatibility and comparability between different classifications and their thematic legends, resulting in map products as independent datasets [44] mainly due to the long-standing lack of coordination among the agencies entrusted with land cover data generation [45]. The development and application

of a standardized and harmonized classification system like the NLRS of Bangladesh offers a new way to represent our environment with the possibility to develop spatial databases in collaboration with several institutions and allowing the development of an integrated and cost-efficient system to meet different objectives of different institutions. Applicability of such approach at regional scale is also recognized by ongoing regional land cover monitoring effort [46].

The lack of interoperability between different land cover datasets, often originating from incompatible land cover classification systems, makes analysis of multi-source, heterogeneous land cover data for various applications a very difficult task [47]. One step toward achieving interoperability is to have means to measure the degree of semantic similarity between existing datasets and the target categorization [48]. The object-oriented automatic similarity assessment of the BFIS geoportal is an important step toward interoperable land cover monitoring and has the potential to contribute in addressing the current challenge of enabling semantic interoperability for comprehensive and reproducible online processing of big Earth observation (EO) data [49].

VII. CONCLUSION

NLRS of Bangladesh is a comprehensive structured list of categories that provides a solid reference to many mapping activities. The land cover dataset of 2015 is serving as a dynamic source of information for several different applications and objectives. The flexibility and interoperability of the dataset is facilitating the process of comparison, the production of consistent statistics, and time-series data.

There has been a long-standing data integration problem in Bangladesh in the domain of land cover mapping in reconciling semantic differences between classification systems. The availability of international standards (i.e., LCML) is an important step to move toward a common syntax for the rationalization and harmonization of national classification systems. However, the generation of a harmonized classification system needs to be put in the proper context. The whole process of the NLRS and land cover map development in Bangladesh acted as a bridge between the data producers by providing a platform to share and document their understanding and knowledge of the data in the form of metadata. This initiative is expected to provide operational guideline that different agencies at national and regional level can use to derive legends that are interoperable and able to better facilitate multipurpose applications.

Additionally, there is much interest in being able to use one thematic dataset as basis for reporting on classes from another classification, for example, because of its better spatial coverage or accuracy. The need to improve the interoperability between datasets can be achieved by overcoming differences in data semantics. In addition to the creation of specific legends for specific applications, the NLRS has also been used as a reference bridging system to compare classes belonging to other existing classifications. It is thus expected that the harmonization of the existing classification systems and development of future

ones, through the NLRS, will help to reduce the reporting burden, thus reducing costs and, in some cases, also improving the quality, robustness, completeness, and transparency of the information.

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REFERENCES

- [1] K. J. Wallace, "Classification of ecosystem services: Problems and solutions," *Biol. Conservation*, vol. 139, pp. 235–246, Oct. 2007.
- [2] R. S. de Groot, M. A. Wilson, and R. M. J. Boumans, "A typology for the classification, description and valuation of ecosystem functions, goods and services," *Ecological Econ.*, vol. 41, pp. 393–408, Jun. 2002.
- [3] A. Di Gregorio, *Land Cover Classification System, Classification Concepts, Software Version 3*. Rome, Italy: Food and Agriculture Organization of the United Nations, 2016.
- [4] A. Comber, P. Fisher, and R. Wadsworth, "Integrating land-cover data with different ontologies: Identifying change from inconsistency," *Int. J. Geographical Inf. Sci.*, vol. 18, pp. 691–708, Oct. 2004.
- [5] G. P. Asner *et al.*, "High-resolution forest carbon stocks and emissions in the Amazon," *Proc. Nat. Acad. Sci.*, vol. 107, pp. 16738–16742, Sep. 2010.
- [6] S. Saatchi *et al.*, "Benchmark map of forest carbon stocks in tropical regions across three continents," *Proc. Nat. Acad. Sci.*, vol. 108, pp. 9899–9904, 2011.
- [7] A. Baccini *et al.*, "Estimated carbon dioxide emissions from tropical deforestation improved by carbon-density maps," *Nature Climate Change*, vol. 2, pp. 182–185, 2012.
- [8] M. C. Hansen *et al.*, "High-resolution global maps of 21st-century forest cover change," *Science*, vol. 342, pp. 850–853, Nov. 2013.
- [9] F. Achard *et al.*, "Determination of tropical deforestation rates and related carbon losses from 1990 to 2010," *Global Change Biol.*, vol. 20, pp. 2540–2554, 2014.
- [10] E. T. Mitchard *et al.*, "Uncertainty in the spatial distribution of tropical forest biomass: A comparison of pan-tropical maps," *Carbon Balance Manage.*, vol. 8, p. 10, 2013.
- [11] UNFCCC, "4/CP.15 methodological guidance for activities relating to 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," in FCCC/CP/2009/11/Add.1, Report of the Conference of the Parties on its 15th Session, Held in Copenhagen from 7 to 19 December 2009, 2009.
- [12] GFOI, *Integrating Remote-Sensing and Ground-Based Observations for Estimation of Emissions and Removals of Greenhouse Gases in Forests: Methods and Guidance from the Global Forest Observations Initiative*. Geneva, Switzerland: Group on Earth Observations, 2014.
- [13] M. Shaheduzzaman and M. Akhter, *Proceedings of the Training Workshop on Land Cover Classification in the Context of REDD+ in Bangladesh, Forest Department, Dhaka, Bangladesh 24–25 March 2013*. UN-REDD Programme. Dhaka, Bangladesh: Food and Agriculture Organization of the United Nations, 2013.
- [14] BFD, *National Forest and Tree Resources Assessment 2005–2007 Bangladesh*. Dhaka, Bangladesh: Bangladesh Forest Department, Ministry of Environment and Forest (MoEF), Food and Agriculture Organization of the United Nations (FAO), 2007.
- [15] H. G. Lund, *Definitions of Forest, Deforestation, Afforestation, and Reforestation*, Aug. 12, 2018. [Online]. Available: https://www.researchgate.net/publication/324755790_2018_Definitions_of_Forest_Deforestation_Afforestation_and_Reforestation
- [16] A. Di Gregorio, *Land Cover Classification System, User Manual, Software Version 3*. UN-REDD Programme. Rome, Italy: Food and Agriculture Organization of the United Nations, 2016.
- [17] GoB, *Land Representation System of Bangladesh (In Support of REDD+)*. Dhaka, Bangladesh: Forest Department, Ministry of Environment, Forest and Climate Change, Government of the People's Republic of Bangladesh, 2017.
- [18] M. Akhter and M. Shaheduzzaman, *Forest Classification Systems in Bangladesh*. UN-REDD Programme. Dhaka, Bangladesh: FAO, 2013.

- [19] BSGI, *Protocol for Land Features Description in Bangladesh: Data Collection Field Manual*. Dhaka, Bangladesh: Bangladesh Forest Department, Center for Environment and Geographic Information System, Bangladesh University of Engineering and Technology, Space Research and Remote Sensing Organization, Soil Resource Development Institute, Food and Agriculture Organization of the United Nations, 2016.
- [20] L. Costello and G. Franceschini, *Proceedings for the Training on National Land Cover Classification Systems Using LCCS3*. Dhaka, Bangladesh: Bangladesh Forest Department and FAO of the United Nations, Nov.–Dec. 2015.
- [21] L. Costello and M. Piazza, *Proceedings from the Training Survey Design and Data Management Using Open Foris Collect for NFI and Carbon Stock Assessment in Bangladesh*. Dhaka, Bangladesh: Food and Agricultural Organization of the United Nations, Nov. 2015.
- [22] A. Di Gregorio, M. Akhter, and M. S. Islam, *Land Cover Classification Systems in the Context of REDD+ in Bangladesh: A Study Analysis Using LCCS3*. Dhaka, Bangladesh: Food and Agricultural Organization of the United Nations, 2014.
- [23] A. Di Gregorio, *Recommendations on the Land and Forest Classification System of Bangladesh, Training Workshop on Land Cover Classification in the context of REDD+ in Bangladesh*. UN-REDD Programme. Dhaka, Bangladesh: Food and Agriculture Organization of the United Nations, 2013.
- [24] A. Hadi, *Proceedings of Training on Translation and Harmonization of SRDI Land Use Map Legend into LCCS (v.3)*. Dhaka, Bangladesh: Food and Agricultural Organization of the United Nations, Feb. 2016.
- [25] A. Hadi, T. Udit, and R. Jalal, *Proceedings of the National Consultation Conference on Land Cover Classification System in Bangladesh*. Dhaka, Bangladesh: FAO of the United National and Bangladesh Forest Department, Mar. 2016.
- [26] A. Hadi, A. U. Khan, M. Kamal, and M. Henry, *Protocol for Land Features Description in Bangladesh: Data Collection Field Manual*. Dhaka, Bangladesh: Bangladesh Society of Geo-informatics, Bangladesh Forest Department and Food and Agricultural Organization of the United Nations, 2016.
- [27] G. Franceschini *et al.*, *Production Chain for Land Cover Mapping in Bangladesh*. Dhaka, Bangladesh: Food and Agriculture Organization of the United Nations, 2016.
- [28] M. S. Islam *et al.*, *Legend for National Land Cover Map*. Dhaka, Bangladesh: Food and Agriculture Organization of the United Nations, 2016.
- [29] T. Udit, G. Franceschini, R. Jalal, and M. Akhter, *Proceedings of the Working Sessions on Supporting the Preparation of the Land Cover Map Development and the Integration of Land Cover and Forest Monitoring*. Dhaka, Bangladesh: Food and Agricultural Organization of the United Nations and Bangladesh Forest Department, Jun. 2016.
- [30] M. Baatz and A. Schäpe, “Multiresolution Segmentation: An Optimization Approach for High Quality Multi-Scale Image Segmentation,” in *Angewandte Geographische Informations-Verarbeitung XIII*, J. Strobl, T. Blaschke, and G. Griesebner, Eds., Heidelberg, Germany: Wichmann, 2000.
- [31] G. Castilla and G. J. Hay, “Image objects and geographic objects,” in *Object-Based Image Analysis: Spatial Concepts for Knowledge-Driven Remote Sensing Applications*, T. Blaschke, S. Lang, and G. J. Hay, Eds., Berlin, Heidelberg, Germany: Springer, 2008, pp. 91–110.
- [32] K. Z. Tasnim, G. Franceschini, and R. Jalal, *Proceedings of the Workshop on the Accuracy Assessment and Quality Checking of Land Cover Map of Bangladesh 2015*. Dhaka, Bangladesh: FAO of the United Nations and Bangladesh Forest Department, Feb. 2017.
- [33] G. M. Foody, “Assessing the accuracy of land cover change with imperfect ground reference data,” *Remote Sens. Environ.*, vol. 114, pp. 2271–2285, Oct. 2010.
- [34] P. Olofsson, G. M. Foody, S. V. Stehman, and C. E. Woodcock, “Making better use of accuracy data in land change studies: Estimating accuracy and area and quantifying uncertainty using stratified estimation,” *Remote Sens. Environ.*, vol. 129, pp. 122–131, Feb. 2013.
- [35] GoB, *Criteria and Indicators of the Bangladesh Forest Inventory*. Dhaka, Bangladesh: Forest Department, Ministry of Environment and Forest, Government of the People’s Republic of Bangladesh, 2017.
- [36] GED, *Seventh Five Year Plan, FY2016–FY2020, Accelerating Growth, Empowering Citizens*. Dhaka, Bangladesh: General Economic Division (GED), Planning Commission, Government of the People’s Republic of Bangladesh, 2015.
- [37] GoB, *Bangladesh Country Investment Plan for Environment, Forestry and Climate Change (2016–2021)*. Dhaka, Bangladesh: The Ministry of Environment and Forests, Government of the People’s Republic of Bangladesh, 2017.
- [38] Z. Iqbal *et al.*, *The Bangladesh Forest Inventory Design: Methodological Approach*. Dhaka, Bangladesh: Food and Agricultural Organization of the United Nations, 2016.
- [39] GoB, *The Socio-Economic Survey of the Bangladesh Forest Inventory*. Dhaka: Forest Department, Ministry of Environment and Forest, Government of the People’s Republic of Bangladesh, 2017.
- [40] GoB, *The Submission of Bangladesh’s Forest Reference Level for REDD+ Under the UNFCCC*. Dhaka, Bangladesh: Bangladesh Forest Department, Ministry of Environment, Forest and Climate Change (MoEFCC), Government of the People’s Republic of Bangladesh, Bangladesh Forest Department, 2018.
- [41] V. P. Peter *et al.*, “Comprehensive monitoring of Bangladesh tree cover inside and outside of forests, 2000–2014,” *Environmental Res. Lett.*, vol. 12, p. 16, 2017.
- [42] A. Di Gregorio, *Object Based Similarity Assessment Method of FAO-LCML Originated Land Cover databases: A Summary*. Dhaka, Bangladesh: Food and Agriculture Organization of the United Nations, 2017.
- [43] K. Uddin *et al.*, “Development of 2010 national land cover database for the Nepal,” *J. Environ. Manage.*, vol. 148, pp. 82–90, Jan. 2015.
- [44] M. Herold *et al.*, “A joint initiative for harmonization and validation of land cover datasets,” *IEEE Trans. Geoscience Remote Sens.*, vol. 44, no. 7, pp. 1719–1727, Jul. 2006.
- [45] J. R. Anderson, E. E. Hardy, J. T. Roach, and R. E. Witmer, *A land use and land cover classification system for use with remote sensor data (- ed.)* [Report], 1976. [Online]. Available: <http://pubs.er.usgs.gov/publication/pp964>
- [46] Servir.icimod.org. *Policy and Planning Workshop on Regional Land Cover Monitoring System*, Sep. 2018. Available: <http://servir.icimod.org/events/policy-and-planning-workshop-on-regional-land-cover-monitoring-system>
- [47] H. Yang, S. Li, J. Chen, X. Zhang, and S. Xu, “The standardization and harmonization of land cover classification systems towards harmonized datasets: A review,” *ISPRS Int. J. Geo-Inf.*, vol. 6, p. 154, 2017.
- [48] C. C. Feng and D. M. Flewelling, “Assessment of semantic similarity between land use/land cover classification systems,” *Comput. Environ. Urban Syst.*, vol. 28, pp. 229–246, May 2004.
- [49] M. Sudmanns, D. Tiede, S. Lang, and A. Baraldi, “Semantic and syntactic interoperability in online processing of big Earth observation data,” *Int. J. Digit. Earth*, vol. 11, pp. 95–112, Jan. 2018.