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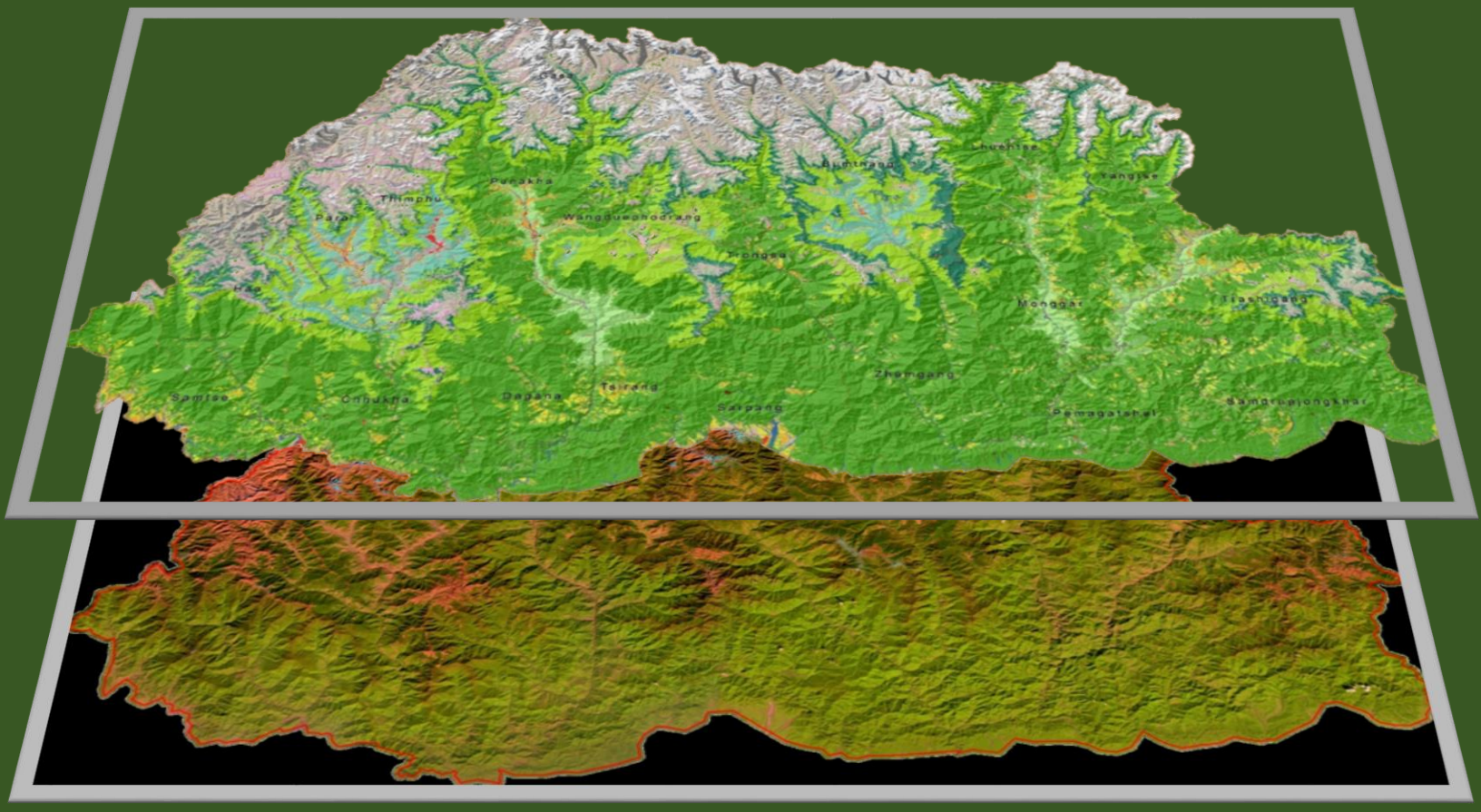
Royal Government of Bhutan

Ministry of Agriculture and Forests

Department of Forests and Park Services

Land Use and Land Cover Assessment of Bhutan2016

Technical Report



Forest Resources Management Division

Land Use and Land Cover Assessment of Bhutan 2016

Technical Report

Forest Resources Management Division

Report Preparation

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Citation

FRMD, 2017; Land Use and Land Cover Assessment of Bhutan 2016, Technical Report

ISBN: 978-99936-743-3-7

དཔལ་ལྡན་འབྲུག་གཞུང་། སོ་ནམ་དང་ནགས་ཚལ་ལྷན་ཐག། ནགས་ཚལ་དང་ཞིང་ཀ་ཞབས་ཏོག་ལས་ཁུངས།

Royal Government of Bhutan
Ministry of Agriculture and Forests
Department of Forests and Park Service
Thimphu: Bhutan

FOREWORD

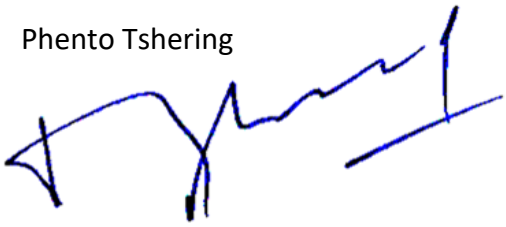
Bhutan is proud of maintaining its large extent of forest cover which is of utmost important owing to our geographical topography. Forest of Bhutan which ranges from dense subtropical to alpine scrub serves as critical habitat to diverse flora and fauna. Besides, forest providing numerous tangible services, it also provides intangible ecosystem services including main source of carbon sink. Constitution has mandated to maintain 60% of forest cover in perpetuity which enable us to preserve our pristine and scenic landscape. However, with recent accelerated developmental activities, monitoring of forest cover has become a crucial activity for Department of Forests and Services.

Monitoring of forest cover through advancing technology like remote sensing has become a critical tool for Bhutan which not only reduce time and human resources but also tremendously reduces financial burden. Therefore, producing periodic land use and land cover map at national level to observe the land use changes taking place is of utmost important. This would not only enable us to monitor the forest cover, forest deforestation and forest degradation but also helps in making strategic decision and formulating policies using the most updated information.

I would like to congratulate Forest Resources Management Division for taking this initiative and successfully completing the land use and land cover (LULC) assessment of Bhutan 2016. Particularly, I would like to commend the work carried out by technical working group; Mr. Arun Rai, FRMD, Mr. Phuntsho, FRMD, Mr. Sonam Penjor, PPD, MoAF, Mr. Rinchen Dorji, UWICER, Mr. Sangay Pelzang, UWICER, Mr. Chenga Tshering, UWICER and Ms. Sangita Pradhan, NSSC under the guidance of Mr. Lobzang Dorji, Chief Forestry Officer, FRMD, DoFPS.

The information and data generated from land use and land cover 2016 are remarkably important for understanding the proportion of land use and land cover area across the landscape of Bhutan. This would not only help to guide our forest monitoring and forest conservation but the information and spatial data will immensely benefit in making plans and policies for sustainable development.

Phento Tshering



Director
Department of Forests and Park Services

Executive Summary

The primary goal of this exercise was to obtain the information on the coverage and distribution of major land use and land cover types of Bhutan to aid strategic and practical resource planning at both national and local levels. The assessment was based on Landsat 8 (OLI). Three winter scenes of 2015 with minimal cloud cover were used for analysis using object based classification in eCognition version 9.1. Extensive validation was carried out using National Forest Inventory(NFI) data, Google Earth and field visit. The overall accuracy of the map was 98.19 %.

Land use and land cover (LULC) 2016 assessment shows a national forest cover of 70.77% of which broadleaf constitutes 45.99%, 13.53% is mixed conifer, 6.02% is fir, 2.64% is blue pine and 2.59% is chir pine. Shrubs and alpine scrubs constitutes 9.74% and 3.39 respectively. Area under cultivated agriculture which includes *Kamzhing, Chhuzhing* and orchards is 2.76%. Meadow which is more concentrated at the higher altitudes covers 2.51% of national geographical area while snow and glaciers cover 5.35%. Built up and non-built up makes 0.2% and 0.02 respectively. Water bodies constitutes 0.65% and rest 4.62% is other land use and land cover which includes rocky outcrops, scree, moraines and landslides.

Zhemgang Dzongkhag has the highest forest cover with 94.2% while Gasa Dzhongkhag has the least area under forest cover with 19%. Similarly, Samtse Dzongkhag has the highest area under cultivated agriculture with 11.46% and Gasa Dzongkhag has the least with only 0.15%.

Acronyms and abbreviations

asl	Above sea level
ALOS	Advanced Land Observing Satellite
AVNIR	Advanced Visible and Near Infrared Radiometer
DANIDA	Danish International Development Agency
DoFPS	Department of Forests and Park Services
FCPF	Forest Carbon Partnership Facility
FRMD	Forest Resources Management Division
GEF	Global Environment Facility
GPS	Global Positioning System
ha	Hectare
IPCC	Intergovernmental Panel on Climate Change
LCMP	Land Cover Mapping Project
LULC	Land Use and Land Cover
LUPP	Land Use Planning Project
m	Meter
MMS	Multispectral Scanner System
MoAF	Ministry of Agriculture and Forests
NFI	National Forest Inventory
NLC	National Land Commission
OLI	Operational Land Imager
RNR	Renewable Natural Resoures
SPOT	Satellite Pour l'Observation de la Terre
TCT	Tasseled Cap Transformation
ToA	Top of atmosphere
UWICER	Ugyen Wangchuck Institute for Conservation and Environmental Research

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1. Introduction

Bhutan is a small mountainous agrarian country. With its large extent of forest cover and perineal flow of river system, country economy is heavily relied on hydropower. Though Bhutan is a small country with small population it is developing at rapid pace. Urbanization is taking place at accelerated rate, remote areas are being connected with farm roads and overall land use change is slowly taking place. The need for having updated and reliable land use and land cover map is indispensable.

The history of Bhutan's land use and land cover mapping dates back to 1970s. However, the first reliable and systematic land use and land cover (LULC) was produced in 1995 through Land Use Planning Project (LUPP) funded by Danish International Development Assistance (DANIDA). During this exercise, SPOT imageries of 1980 to 1990 and aerial photographs was used. Second land use and land cover assessment was carried out in 2010 through land cover mapping projected funded by Global Environment Facility (GEF)/World Bank funded sustainable land management project (SLMP). During the second LULC assessment, ALOS imageries (AVNIR-2) of 2006 to 2009 winter scene with 10m spatial resolution were used.

Third LULC assessment was carried out in 2016 using Landsat satellite imageries with financial support from Forest Carbon Partnership Facility (FCPF) delivered through World Bank in order to supplement the National Forest Inventory exercise and also to monitor the land cover change over the period.

2. Objectives

The main objectives of this exercise is to:

1. Update the land use and land cover map
2. To monitor the health and state of Bhutan's forest for enabling long-term conservation and maintaining 60% of forest cover in perpetuity
3. To generate accurate and holistic information on forest area and carbon stock change in a transparent and consistent manner.

3. Material and Methodology

3.1 Satellite Image

For generating Land Use and Land Cover (LULC) map 2016, Landsat 8 (OLI) of November to December 2015 were used. Landsat 8 was lunched in 11th February, 2011 (https://landsat.gsfc.nasa.gov/landsat-8/landsat-8-overview) and it has two sensors: Operational Land Imager (OLI) and Thermal Infrared Sensors (TIRS). Two sensors provide global coverage at a spatial resolution of 30m (visible, NIR, SWIR), 100m (thermal) and 15m (panchromatic). Detail of Landsat 8 band is given in Table 1.

Table 1 Band details of Landsat 8 (OLI)

Band	Wavelength (micrometer)	Resolution (meter)
Band 1 – Ultra Blue (Coastal/aerosol)	0.43 - 0.45	30
Band 2 – Blue	0.45 – 0.51	30
Band 3 – Green	0.53 – 0.59	30
Band 4 – Red	0.64 – 0.67	30
Band 5 – Near Infrared (NIR)	0.85 – 0.88	30
Band 6 – Shortwave Infrared (SWIR) 1	1.57 – 1.65	30
Band 7 – Shortwave Infrared (SWIR) 2	2.11 – 2.29	30
Band 8 – Panchromatic	0.50 – 0.68	15
Band 9 – Cirrus	1.36 – 1.38	30
Band 10 – Thermal Infrared (TIRS) 1	10.60 – 11.19	100 * (30)
Band 11 – Thermal Infrared (TIRS) 2	11.50 – 12.51	100 * (30)

*TIRS band are acquired at 100meter resolution, but product is delivered at 30 meter resolution after resampling.

Landsat 8 have temporal resolution of 16 days and product are consistent with Landsat 1 to Landsat 7 (https://landsat.usgs.gov/landsat-8). Level 1T (Terrain corrected) products are available for download at free of charge from GloVis, EarthExplorer or via LandsatLook Viewer.

Three Landsat 8 scenes covers the entire Bhutan (path 137 and row 41, path 138 and row 41 and path 139 and row 41). Winter scenes of following dates (Table 2) were download from GloVis to be used for analysis.

Table 2 Detail of Landsat 8 (OLI) path/row and image acquisition date

Path and Row	Acquisition Date
137/41	12th November 2015
138/41	19th November 2015
139/41	28th December 2015

3.2 Software

For this assessment the following software were used:

1. ERDAS IMAGINE
2. ArcGIS
3. QGIS and
4. eCognition

3.3 Satellite Image Preprocessing

3.3.1 Top of Atmosphere (ToA)

Solar radiation reflected by the Earth's Surface to satellite sensors is altered by its interaction with the atmosphere. This interaction is enhanced when target surface is non-bright object like water and vegetation. Such problem is significant when multi spectral satellite data is used (Hadjimitsis et al., 2010). Therefore, removal of atmospheric effect is important pre-processing step required in remote sensing, especially when optical sensor data is used.

Individual band of three scenes were converted into top of atmosphere in QGIS using the given formula.

$$\rho\lambda' = M\rho Qcal + A\rho$$

where:

ρλ' *= TOA planetary reflectance, without correction for solar angle. Note that* ρλ' *does not contain a correction for the sun angle.*
Mρ *= Band-specific multiplicative rescaling factor from the metadata (REFLECTANCE_MULT_BAND_x, where x is the band number)*
Aρ *= Band-specific additive rescaling factor from the metadata (REFLECTANCE_ADD_BAND_x, where x is the band number)*
Qcal *= Quantized and calibrated standard product pixel values (DN)*

3.3.2 Stacking

Individual bands of each scene were stacked in ERDAS IMAGINE. Individual bands were grouped into three categories for stacking owing to their differences in spatial resolution. Band 1 to Band 7 were stacked as one layer and band 9 to band 11 were stacked into different layer, leaving band 8 as standalone layer. This process was repeated for all three different scenes.

3.3.3 Projection

Landsat 8 imageries were in WGS 1984 UTM zone 45 and 46. Bhutan has its own coordinate system called "Drukref03". All Landsat 8 imageries were re-projected to Drukref03 in ERDAS IMAGINE.

3.3.4 Image Mosaic

Three different scenes (Figure1) cover the entire geographical area of Bhutan. Scene 137/41 covers the Eastern part, 138/41 covers the Western part and 139/41 cover tiny part of extreme Western part of Bhutan.

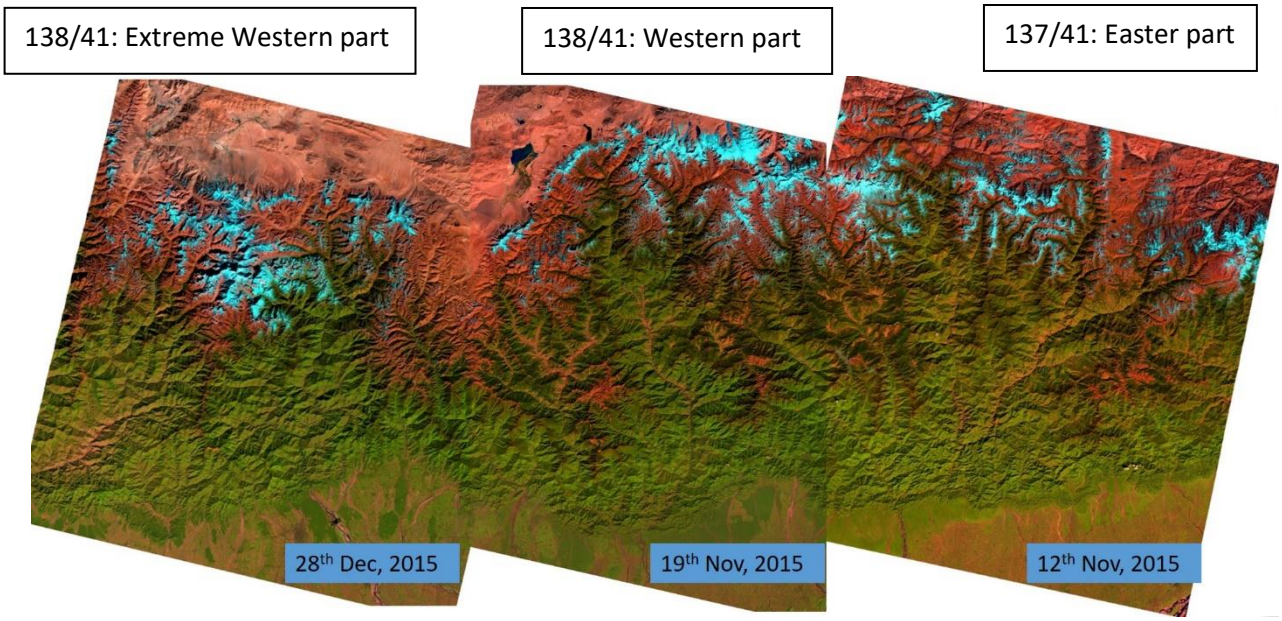

Figure 1 Three landsat 8 (OLI) scenes for Bhutan

Three individual scenes were mosaicked in ERDAS IMAGINE using MosaicPro tools. Seamline generation method applied was Most Nadir Seamline with smoothing of 500m under smoothing filter of 8X8 low pass and feathering of 500m. The process was iterated for all three layers (band 1 to 7), (band 8) and (band 9 to band 11). Then mosaicked image was clipped to the shape of Bhutan with 2km buffer as shown in figure 3,4 and 5.

Figure 2 Mosaic of band 1 to 7 Landsat 8 (OLI)

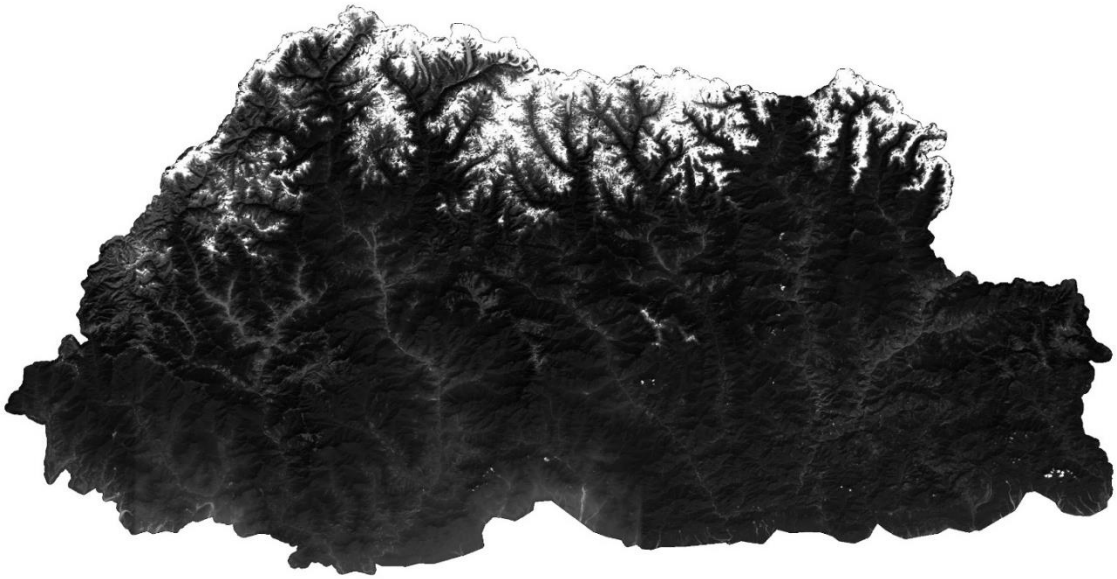

Figure 3 Panchromatic band (band 8) Landsat 8 (OLI)

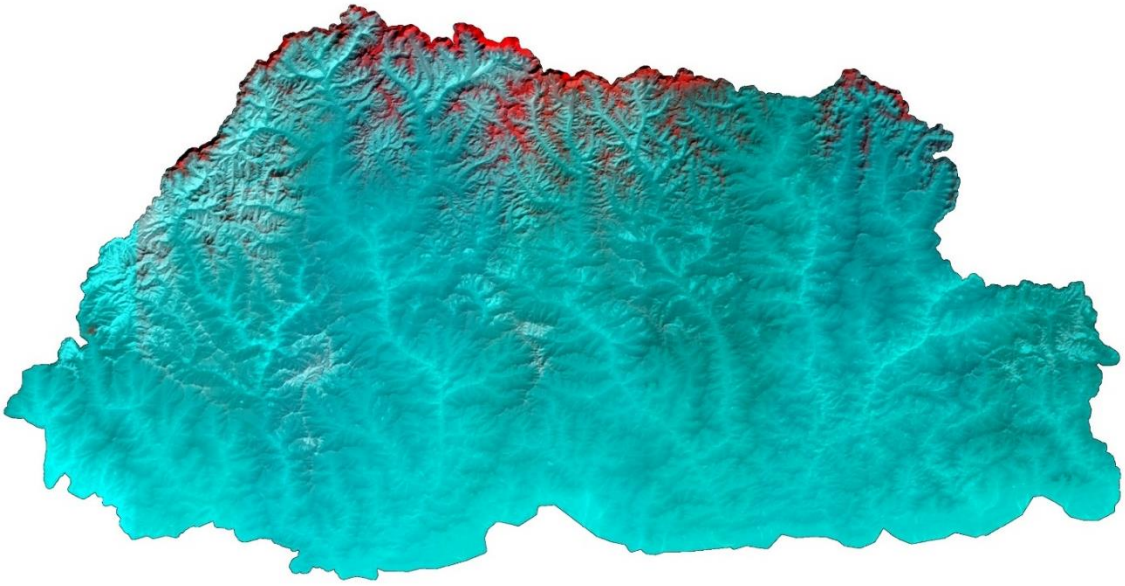

Figure 4 Mosaic of band 9 to 11 Landsat 8 (OLI)

3.4 Band Ratioing

Band ratioing is one of the most common technique used to reduce the topographical interference in remote sensing. Sometime difference in brightness value from identical surface materials are caused by topographic slope, aspect, shadows, or seasonal changes in sunlight illumination angle and intensity. These condition hampers the image interpretation. Thereby, band ratioing reduce environmental effect and enhance the data. Band ratioing consists of dividing the radiance value in one channel by the corresponding radiance value in second channel (Holben et al., 2010). By ratioing the data from two different spectral bands, the resultant image

enhances variation in the slopes of the spectral reflectance curve between the two different spectral ranges that may otherwise be masked by the pixel brightness variation in each of the bands. In addition to this, band ratioing may also provide unique information not available in any single band for discriminating between different land use and land cover classes.

Band ratioing techniques are described in Table 3 which was carried out in eCognition and ERDAS IMAGINE.

Table 3 Indices calculation

Ratio	Formula
Normalized Difference Vegetation Index (NDVI)	(NIR-R)/(NIR+R)
Normalized Difference Water Index (NDWI)	(NIR-G)/(NIR+G)
Normalized Difference Snow Index (NDSI)	(G-SWIR1)/(G+SWIR1)
Normalized Difference Building Index (NDBI)	(SWIR1-NIR)/(SWIR1+NIR)
Normalized Difference Bareness Index (NDBaI)	(SWIR1-TIRS1)/(SWIR1+TIRS1)
Enhanced Built up and bareness Index (EBBI)	(SWIR1-NIR)/Squrt(SWIR1+TIRS1)
Transformed NDVI (TNDVI)	Squrt((NIR-RED)/(NIR+RED)+0.5)

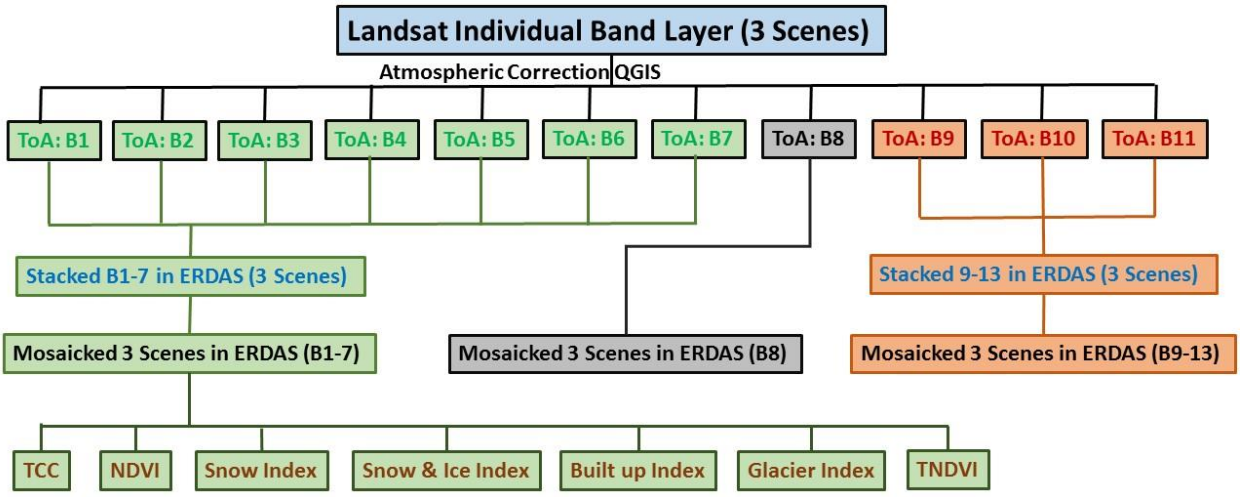

Figure 5 Diagrammatic representation of Image preprocessing

3.5 Tasseled Cap Calculation

Tasseled cap transformation (TCT) is conversion of an image into a new set of band with defined interpretations that are useful for mapping purpose. Tasseled cap transformation is performed by taking linear combination of the original band, in similar concept to principal component analysis. Tasseled cap transformation was developed by Kauth and Thomas in 1976 for Landsat MSS data (Kauth et al., 1976) and was improved and extended for other Landsat as well. Coefficients used for the transformation are derived statistically from images and empirical observation which are specific to each imaging sensor.

During this exercise, tasseled cap transformation was carried out in ERDAS IMAGINE using the coefficient developed by Muhammad Hasan Ali et al. (2014). TCT coefficient is given in Table 4.

Table 4 TCT coefficient for Landsat 8

Landsat 8 band/TCT	Band1	Band2	Band3	Band4	Band5	Band6	Band7
Brightness	0.0000	0.3029	0.2786	0.4733	0.5599	0.5080	0.1872
Greenness	0.0000	-0.2941	-0.2430	-0.5424	0.7276	0.0713	-0.1608
Wetness	0.0000	0.1511	0.1973	0.3283	0.3407	-0.7117	-0.4559
TCT4	0.0000	-0.8239	0.0849	0.4396	-0.0580	0.2013	-0.2773
TCT5	0.0000	-0.3294	0.0557	0.1056	0.1855	-0.4349	0.8085
TCT6	0.0000	0.1079	-0.9023	0.4119	0.0575	-0.0259	0.0252

3.6 Land Use and Land Cover Classes

Land use and land cover classes are adopted similar to LCMP2010. Beside, land use class requirement as per the IPCC reporting (Penman et al., 2003) were also considered. The current classification system has 12 main classes with 12 sub classes (Table 5).

Table 5 Land use and land cover classes

Class	Sub-class	Symbol
Forest	Mixed Conifer forest	FCm
	Blue pine forest	FCb
	Fir forest	FCf
	Chir pine forest	FCc
	Broadleaf forest	FB
Alpine Scrub		AS
Shrub		SH
Meadows		Md
Cultivated Agricultural Land	Chhuzhing	AC
	Kamzhing	AK
	Orchard	AO
Built Up Areas		BA
Non Built Up Areas		NBA
Water Bodies	Lakes	WL
	Rivers	WR
Snow and Glacier		SG
Moraines		Mo
Landslide		Ls
Rocky Outcrops	Scree	Sr
	Rocky Outcrops	RO

3.7 Description of Classes

I. FORESTS

Forests means land with trees spanning more than 0.5 hectares with trees higher than 5 meters and a canopy cover of more than 10 percent. It does not include land that is predominantly under agricultural or urban land use (National Forest Policy of Bhutan, 2011). This class is further divided into different forest type.

I.I *Blue Pine Forest (FCb)*

The "Blue Pine Forest" consists of pure or dominant stands of blue pine, usually at an altitude between 1500m and 3200m asl. Smaller areas of mixed conifers and broadleaf forest may occur interspersed in the blue pine mapping unit, but because of their small areas they are often left unrecorded.

I.II *Chir Pine Forest (FCc)*

The "Chir Pine Forest" consists normally of pure stands of chir pine, usually at altitudes between 700m and 2000m asl. at relatively dry areas. However, in depressions and water courses, broadleaf might occur but these areas are usually small and included within the chir pine mapping unit.

I.III *Mixed Conifer Forest (FCmc)*

The "Mixed Conifer Forest" includes mixed stands of spruce, hemlock, juniper, fir, larch, taxus and blue pine. Some broadleaf inclusions are also common particularly oaks, rhododendron, maple and birch. It usually occurs between 2500m and 3500m asl.

I.IV *Fir Forest (FCf)*

The "Fir Forest" consists either of largely pure stands of fir or few stands of other species such as junipers, taxus and larch. This category occurs mostly above 3000m asl.

I.V *Broadleaf Forest (FB)*

The "Broadleaf Forest" consists of dominantly broadleaf trees. Commonly broadleaf forest is found below 3000m asl. In some case broadleaf is mixed with few stand of other conifer species, however, owing to the smaller area, it is mapped under broadleaf forest.

II. ALPINE SCRUB (AS)

Alpine scrub is woody plant characterized by stunted growth (height less than 5meter) due to harsh condition. They are found at higher elevation above 3500 meter asl. close to tree line. Predominant species includes dwarf rhododendrons and junipers.

III. SHRUBS (SH)

Shrubs are perennial plants with persistent and woody stem without any defined main stem with height less than 5 meter. It also includes abandoned agricultural fields with overgrown bushes and other regeneration in disturbed areas.

IV. MEADOWS (Md)

Meadows include any areas dominated by grasses or any herbaceous plant without or with few scattered trees or shrubs on it. It occurs at all elevations, but is relatively more common at higher elevations.

V. CULTIVATED AGRICULTURAL LAND

Cultivated agricultural land includes only those agricultural land that are cultivated at the time of land cover assessment. It is further divided into sub classes.

V.I *Chhuzhing (AC)*

Chhuzhing means irrigated and or bench terraced agricultural land for paddy based cropping systems.

V.II *Kamzhing (AK)*

Kamzhing refers to cultivated rain-fed areas (dry land). Some *Kamzhing* lands have certain level of land shaping.

V.III ORCHARD (AO)

Orchard refers to planted fruit bearing trees like apple, orange, areca nut, etc.

VI. BUILT UP AREAS (BA)

Built up areas includes artificial constructions covering the land with an impervious (e.g. concrete, CGI sheet, thatch) surface. It includes airport, rural settlements, urban areas, schools & institutes, industrial areas, hospital premises, sewage treatment plant, sports and leisure facilities and roads.

VII. NON BUILT UP AREAS (NBA)

This class is defined by absence of the original (semi-) natural cover mainly due to anthropogenic factors. It includes waste dump sites, mines, stone quarries and other extraction sites.

VIII. WATER BODIES

This class includes both natural and artificially created water bodies. It is further dived into two sub classes:

IX.I *Lakes (WL)*

Lakes refers the area of perennial and natural water surrounded by land. It includes both natural and manmade.

IX.II *Rivers (WR)*

Rivers refers to perennial flow of water and the river beds. It also includes artificially constructed reservoir (dam) along the course of perennial rivers.

IX.SNOW AND GLACIERS (SG)

This class includes both perpetual and seasonal snow cover and glaciers.

X. MORAINES (Mo)

Moraines refers to a mass of rocks and sediments carried down and deposited by a glacier typically as ridges at its edges or extremity.

XI. SCREE (Sr)

Scree refers to a mass of small loose stones that form or cover a slope on a mountain.

XII. LANDSLIDE (Ls)

This class includes mass movement of soils debris due to gravitational force triggered by other factors such as rainfall and earthquakes.

XIII. ROCKY OUTCROPS (RO)

Rocky outcrops refer to natural cliffs and rocky areas.

3.8 Image Classification

Image classification is process to categorize all pixels in a digital image (satellite imageries) into land use and land cover classes or themes. Normally multispectral imageries are used for classification, the spectral value present within each pixel is the numerical basis for classification (Lucas, 1995). Over the years, there are numerous ways developed for classifying satellite imageries. Most commonly used methods for classification are supervised and unsupervised classification. Recently the scientists and researchers have been inclining towards object based classification and it has proven to outperform the former classification methodology (Weih et al., 2010), (Hussain et al., 2013; Jingxiao et al., 2014). Object based classification aggregates the pixel by means of image segmentation which divides the image into group of pixels (called object) aggregating them according to criteria likened not only to the spectrum, but also to the shape and homogeneity.

Image classification for LULC 2016 assessment is object based classification which was carried out in eCognition 9.1. All the mosaicked landsat8 image and generated indices (ratioing) layers were uploaded in eCognition as an individual layer. This software has a capability to analyze both raster and vector files simultaneously. Cadastral data was uploaded as vector file to ease the classification of registered land which is primarily focused in agricultural classification. Pictorial representation of classification process is given in Figure 6.

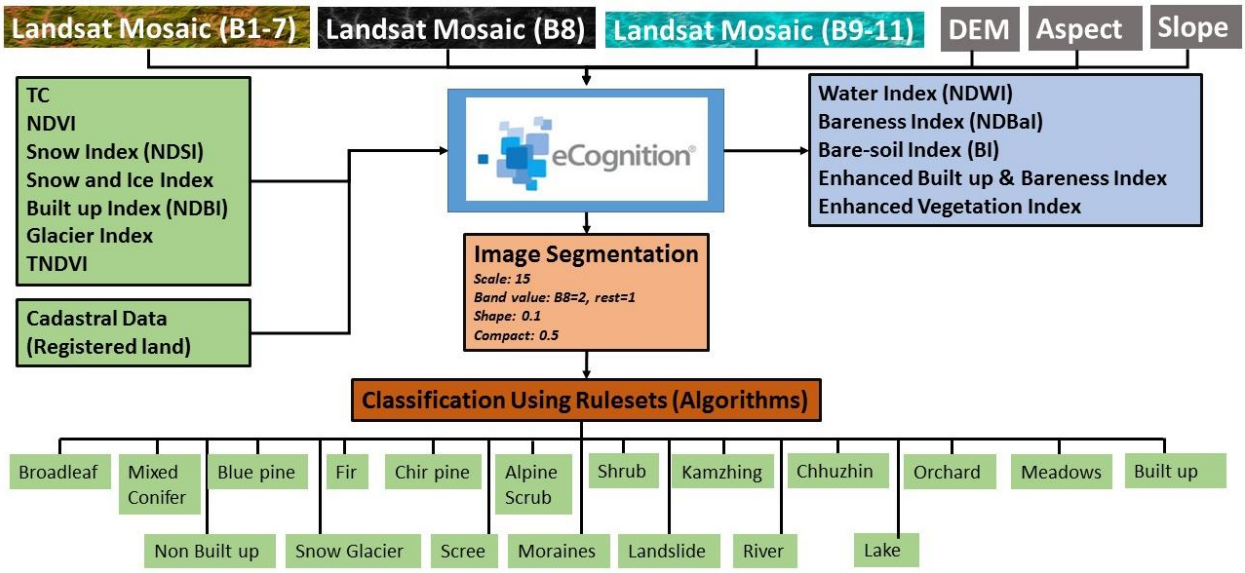

Figure 6 Overall process of image classification in eCognition

3.8.1 Segmentation

Image segmentation is prerequisite step for object based image classification. Image segmentation is generally defined as a process of partitioning an image into homogenous group or pixel (Dey et al., 2010). It is important to understand that overall classification of an image depend upon the successful image segmentation. There are different types of image segmentation technique. In this exercise, multiresolution image segmentation was applied where corresponding parameter were set as;

Scale =15

Band value = band 1 to 7 =1, band 8=2 and band 9 to 11= 1

Shape = 0.1

Compact = 0.5

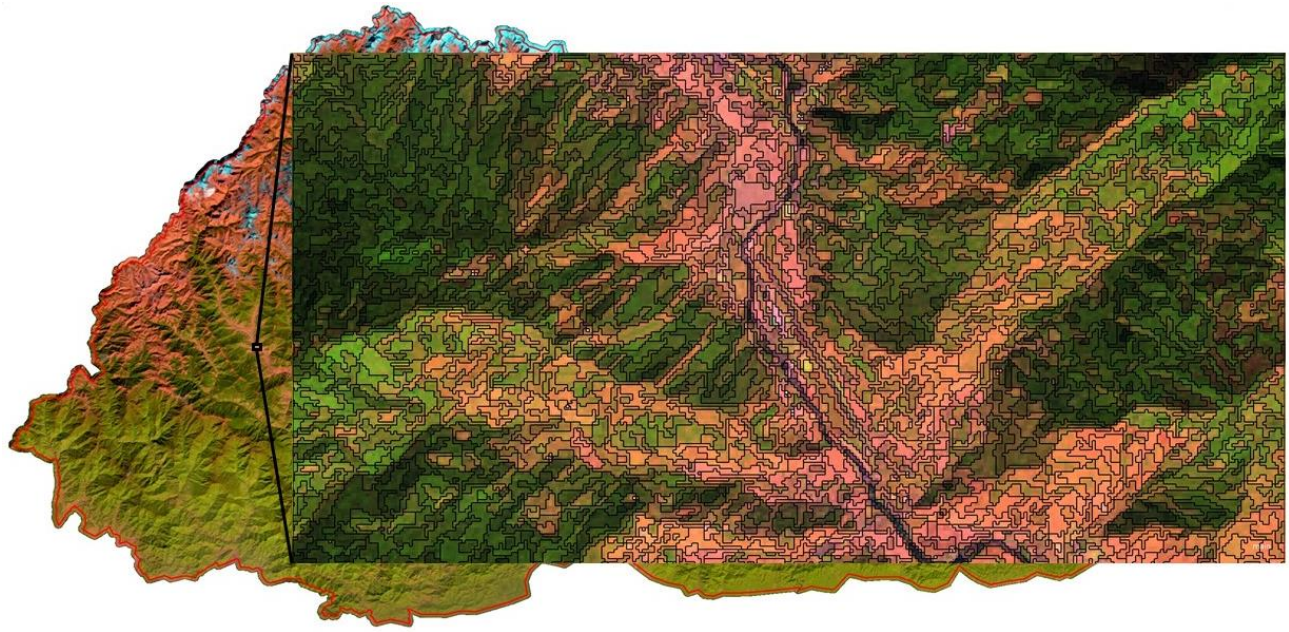

Figure 7 Image segmentation

3.8.2 Classifying land use and land cover type

Automatic rule based classification followed by manual correction was applied to correctly classify each individual classes. Such method is often referred as hybrid approach. Classification of each individual class was carried out in sequential step.

I. Lake

Lake were easier to classify from other classes owing to its shape. Ruleset applied to classify the lake:

i. Unclassified segment with mean NDVI ≤ -0.25 = Lake (From unclassified segments classified as LAKE).
ii. Classified lake with mean NDWI ≥ -0.5 = unclassified (Removed shadow which was classified as LAKE).

II. Snow and Glacier

Satellite image (Landsat8) used for classification were winter scenes, therefore, snow cover at the higher altitude was prominent. Ruleset applied were:

i. Unclassified segment with mean coastal ≥ 300 = SNOW
ii. Unclassified segment with mean Wetness ≥ 37 = SNOW
iii. Classified snow with DEM (elevation) ≤ 3700 = unclassified (Removed cloud which was classified as SNOW)

III. Rivers

Classification of river using only automatic rule based approach did not generate desired result. Therefore, it was a necessity step to supplement with manual correction to achieve the desired result. Ruleset applied were;

i. Unclassified segment with mean NDWI ≥ -0.4 = Rivers
ii. Classified Rivers with mean Aspect ≥ 270^{o} = unclassified (Removed shadow that was classified as Rivers)
iii. Classified Rivers with mean NDVI ≥ 0.5 = unclassified (Removed shadow that was classified as Rivers)
iv. Classified Rivers with mean NDBaI (Build up index) ≥ -0.65 = unclassified (Remove bare areas that was classified as Rivers)
v. Classified Rivers with DEM (elevation) ≥ 3000 = unclassified (removed small tributaries mixed with other land class)
vi. Manual Correction (Removed other segments which were not rivers but were classified as rivers)

IV. Vegetation vs Non Vegetation

After classifying lakes, snow glaciers and rivers, the next step followed was to differentiate between vegetated area and non-vegetated area. Ruleset applied were:

i. Unclassified segment with mean NDBaI ≥ -0.62 = Non vegetated area

V. Classification of Non forest

i. Unclassified segment with mean NDBaI ≥ -0.75 = Non Forest (Non forest includes alpine scrub, shrub, meadow and agriculture)
ii. Classified Non Forest with mean NDVI ≥ 0.47 = unclassified (Removed forest that was classified as Non Forest)
iii. Manual correction due to shadow

VI. Classification of forest

i. Unclassified segment with mean TNDVI ≤ 0.638 = Forest
ii. Classified Forest with DEM (elevation) ≥ 4500 is unclassified from Forest (Removed vegetation that was classified as Forest above 4500m asl.)

VII. Classification of Broadleaf Forest

i. Classified Forest with TCT4 ≤ -38.8 = Broadleaf
ii. Classified Broadleaf with DEM (elevation) ≥ 3500 = Mixed Conifer (Removed Broadleaf above 3500m asl. Usually above 3500m asl. forest type is dominated by coniferous forest).

VIII. Classification of Mixed Conifer

i. Classified Forest with TCT4 > -38.8 = Mixed Conifer

IX. Classification of Blue pine

i. Classified Mixed Conifer with Quantile TCT6 at 65 ≤ -16 = Blue pine
ii. Classified Blue pine with DEM (elevation) ≥ 4000 = Mixed Conifer (Removed Blue pine that was classified above 4000m asl. and convert back to Mixed Conifer)
iii. Manual Correction

X. Classification of Fir

i. Classified Mixed Conifer with TCT6 ≥ -11.5 = Fir
ii. Classified Mixed Conifer with DEM (elevation) ≥ 3700 = Fir
iii. Classified Fir with DEM (elevation) ≤ 2000 = Mixed Conifer (Removed Fir below 2000m asl. and convert to Mixed Conifer).

XI. Classification of Chir pine

i. Classified Broadleaf with Quantile TCT6 at 65 ≤ -18.5 and Qunatile TCT 6 at 65 ≥ -28 = Chir pine.
ii. Classified Chir pine with TCT4 ≤ -55 = Broadleaf (Removed over classified Chir pine)
iii. Classified Chir pine with DEM (elevation) ≥ 2000 = Broadleaf (Removed Chir pine that was classified above 2000m asl. Usually Chir pine is found below 2000m asl.).
iv. Classified Chir pine with DEM (elevation) ≤ 500 = Broadleaf (Removed Chir pine that was classified below 500m asl. Usually Chir pine is not found below 500m asl.).
v. Manual Correction

XII. Classification of cultivated agriculture (*Chhuzing* and *Kamzhing*)

To classify *Chhuzhing* and *Kamzhing*, cadastral data (NLC) was used. After creating two classes, overlapping segments with cadastral polygon were converted into corresponding classes.

i. Maximum overlapping (with thematic polygon) ≥ 30 is classified as *Chhuzing* or *Kamzhing*

XIII. Classification of Meadow

i. Classified Non Forest with mean RED ≥ 85 = Meadow
ii. Classified Meadow with mean SWIR1 ≤ 263 Non forest (Removed over and misclassification of Meadow)

XIV. Classification of Built up

i. Classified Non vegetated area with TCT6 ≤ -19 = Built up
ii. Built up with DEM (elevation) ≥ 3500 = Non vegetated Area

XV. Classification of Scree

i. Classified non vegetated area with mean NDVI ≤ 0 .08 = Scree
ii. Classified Non forest with mean NDVI ≤ 0 .08 = Scree

XVI. Classification of Shrubs

i. Remaining Non Forest (remaining after classifying meadow and agriculture) = Shrub
ii. Remaining Non vegetated area = Shrub
iii. Remaining unclassified segment (if any) = Shrub

XVII. Classification of Alpine scrub

i. Classified Shrub with mean NDVI ≥ 0.38 = Alpine Scrub
ii. Classified Shrub with DEM(elevation) ≥ 4000 = Alpine Scrub

XVIII. Classification of Orchard

Orchard were very difficult to distinguish from forest due to it similar spectral signature.

i. Manual correction after validating from Google Earth

XIX. Classification of Landslide

i. Manual correction after validating from Google Earth

XX. Classification of Non Built up

i. Manual correction after validating from Google Earth

The overall methodology and classification process is diagrammatically represented in Figure 8 below.

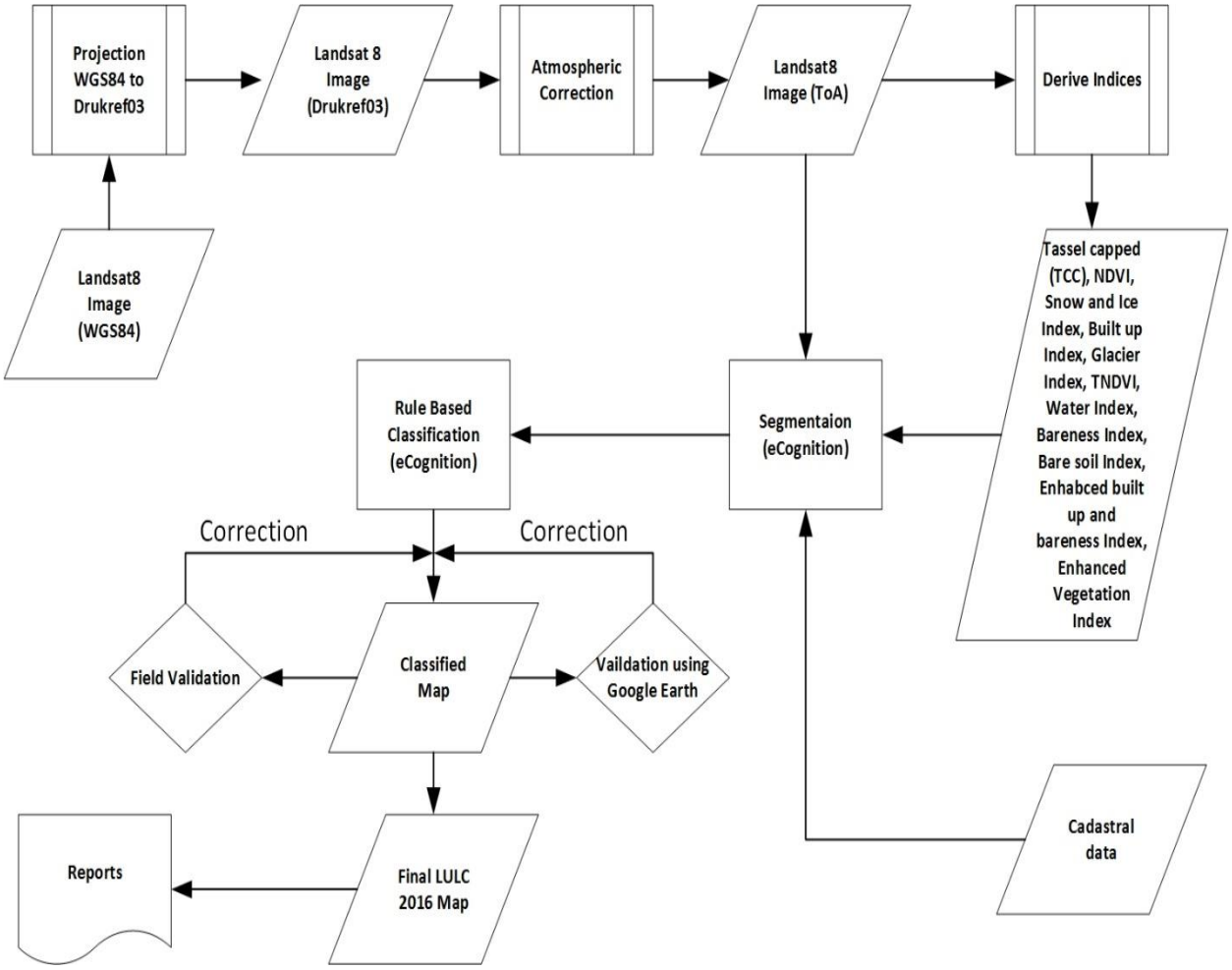

Figure 8 Flow diagram of overall process of LULC2016 generation

4. Validation

In Bhutan, given the mountainous terrain, area falling under the shadow was a challenge to obtain accurate classification using only algorithm. Another area of difficulties was distinguishing between the different vegetation cover having close phenotype characteristics. Distinguishing between shrubs and agriculture land was another challenge based only on spectral signature. To address the misclassification, the first draft LULC map was validated using Google Earth, NFI data and national cadastral data. Further, field visit was carried out to increase the accuracy and precision of the map.

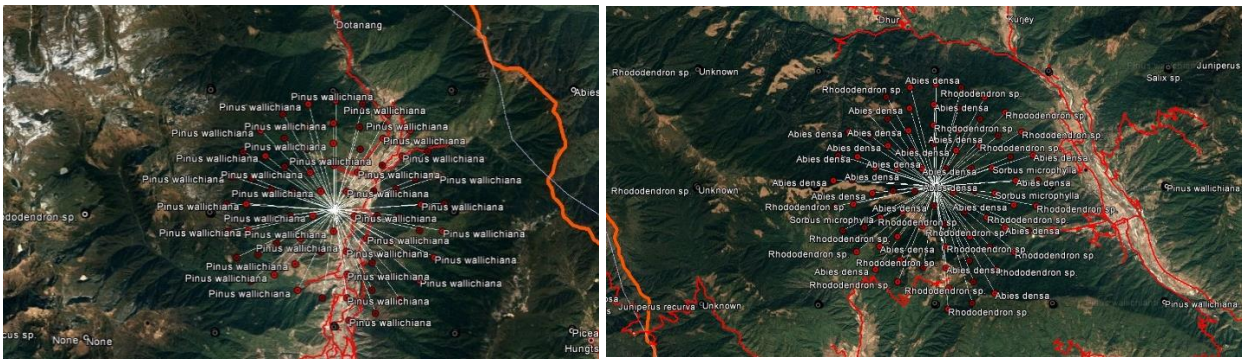

Figure 9 NFI data used for validation

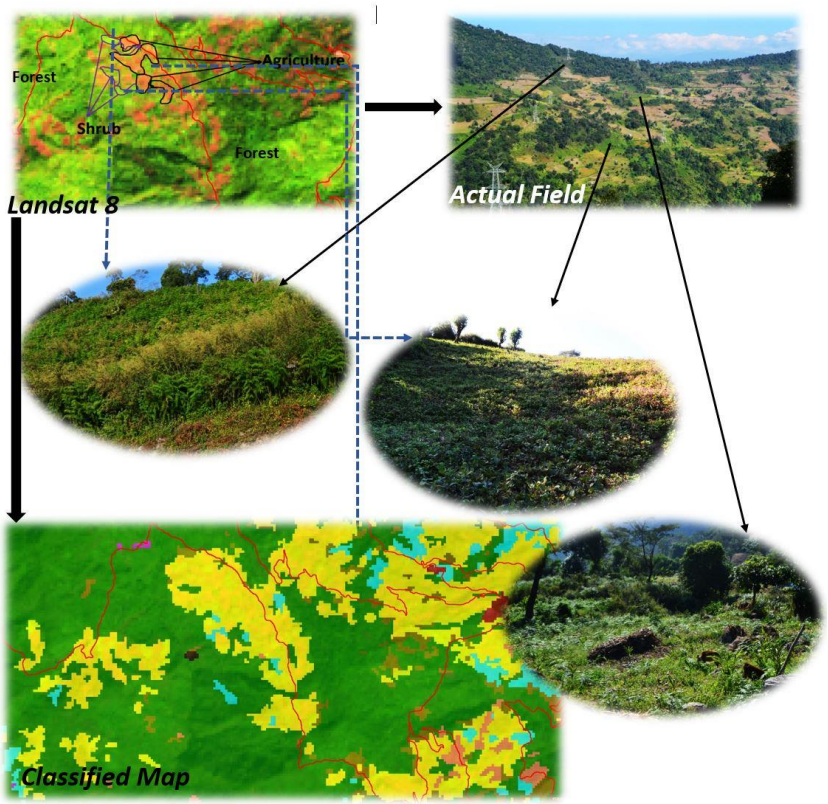

Figure 10 Field validation (shrubs and agriculture)

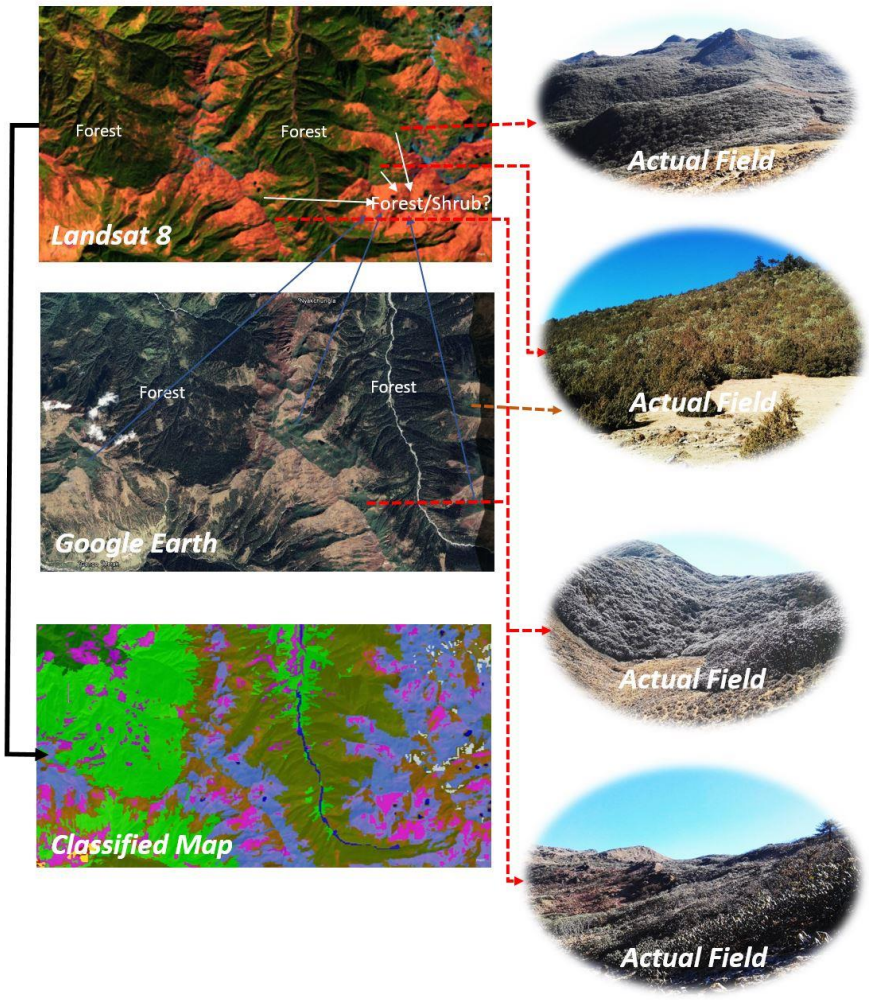

Figure 11 Field validation (Forest and Alpine scrub)

5. Accuracy Assessment

According to Anderson *et all*. (1976), the minimum level of interpretation accuracy in the identification of land use and land cover categories from remote sensor data should be at least 85 percent. The most widely used methodology to carry out the map accuracy assessment is error matrix method (Manandhar et al., 2009). This method is very effective in presenting accuracies in each category with both error of inclusion (commission errors) and error of exclusion (omission errors) present in classification (Congalton, 1991).

For carrying out the accuracy assessment, National Forest Inventory Data (NFI) relevant to corresponding land use and land cover were used as ground data. Part of ground data which was missing from NFI were collected using GPS during the field validation and partly it was randomly extracted from high resolution image (Google Earth). Minimum of 50 to maximum of 150 ground

points were collected for each land use and land cover classes. Error matrix method was adopted to assess the accuracies of map.

Overall accuracy is the total number of correctly classified sample (diagonal cell of the matrix) divided by the total number of samples. It measures the accuracy of entire image without indication of individual class accuracy (Story et al., 1986). The producer's accuracy is the number of correctly classified samples of a particular class divided by the total number of reference sample of that class. It is also measure of error of omission (Story et al., 1986). User's accuracy is the number of correctly classified samples of particular class divided by the total number of samples being classified as that class. It measures the error of commission (Story et al., 1986).

The overall accuracy of the map is 98.19%. The Producer's accuracy and User's accuracy is as follows for each class.

Table 6 Producers and Users accuracy of individual class

Class Name	Producers Accuracy	Users Accuracy
Lake	98.81%	100.00%
Snow and Glacier	100.00%	100.00%
Rivers	100.00%	100.00%
Broadleaf	97.06%	96.12%
Mixed Conifer	95.51%	97.70%
Chir pine	97.47%	97.47%
Fir	96.05%	98.65%
Blue pine	98.53%	95.71%
Chhuzhing	100.00%	100.00%
Scree	95.45%	94.38%
Built up	100.00%	100.00%
Meadows	100.00%	99.01%
Shrub	98.88%	93.62%
Landslide	100.00%	100.00%
Orchard	95.00%	95.00%
Kamzhing	100.00%	98.85%
Non-built up	80.77%	100.00%
Rocky outcrop	95.24%	96.39%
Moraine	100.00%	100.00%
Alpine Scrub	100.00%	100.00%

Average producer accuracy is 97.44% while the average user's accuracy is 98.15%. Kappa coefficient (Cohen, 1960) which measures the agreement between classification and reference data (ground data) is 0.98.

6. RESULTS

In LULC 2016 map, forests dominate the Bhutan's landscape with 70.77%. This is followed by alpine scrub (3.39%) and shrubs (9.74%). Area under cultivated agricultural lands is 2.75% which is equivalent to **105682.43 ha.** Snow cover and glacier constitutes 5.35% while rocky outcrops and scree together makes 4.15%. Area covered by meadow is 2.51%. Built up and Non built up makes 0.19% and 0.02 respectively. Water bodies which includes lakes and rivers constitutes 0.65%. Rest 0.47% is constituted by moraines and landslides.

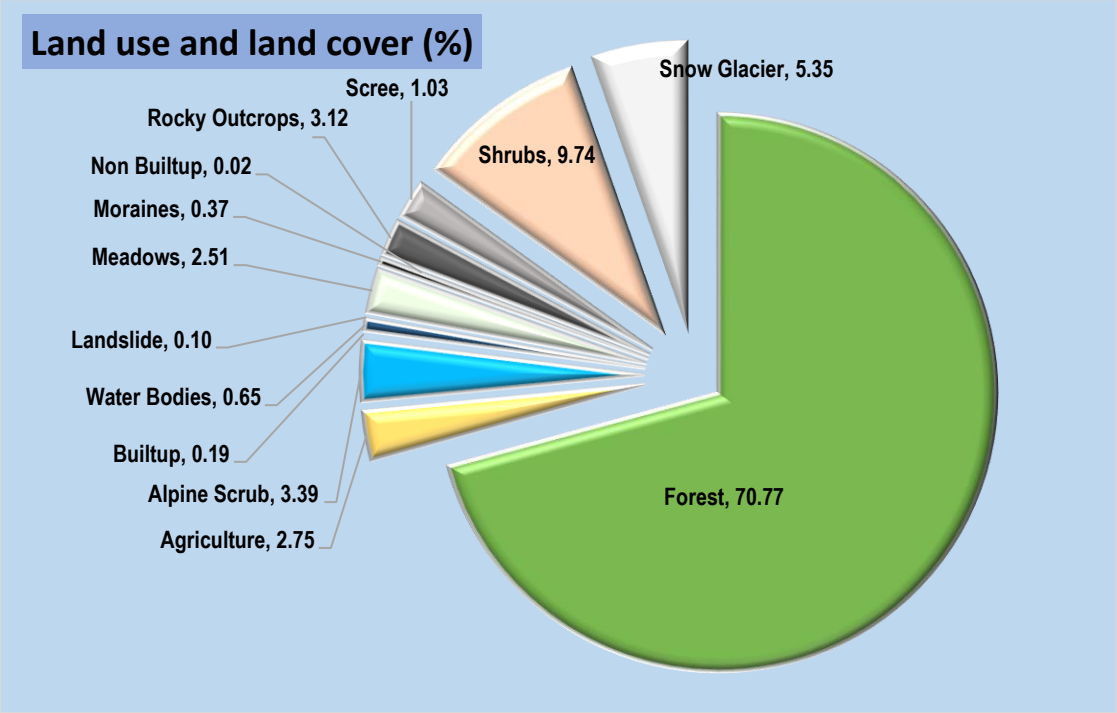

Figure 12 Graphical representation of land use and land cover of Bhutan

Total forest cover of Bhutan is 70.77%, where broadleaf dominates with 45.94% followed by mixed conifer with 13.53%. Fir which usually dominates at the higher altitude makes 6.02% while blue pine constitutes 2.64%. Chir pine constitutes 2.64%.

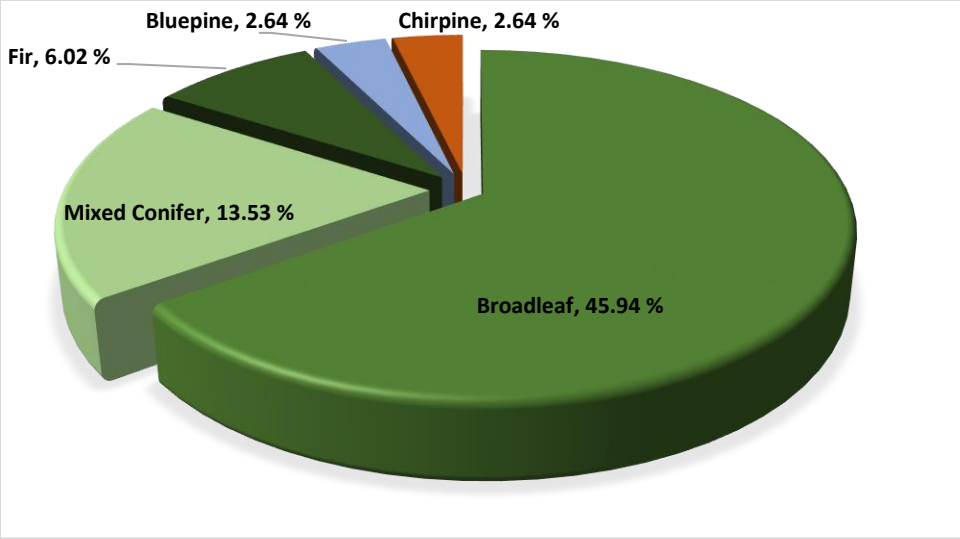

Figure 13 Graphical representation of forest types of Bhutan

Cultivated agriculture constitutes 2.75% dominated by *kamzhing* (arable dryland) with 1.78% equivalent to 68260.64 ha followed by *chhuzhing* (paddy cultivation) with 0.83% (31891.87 ha) and orchards makes 0.14%.

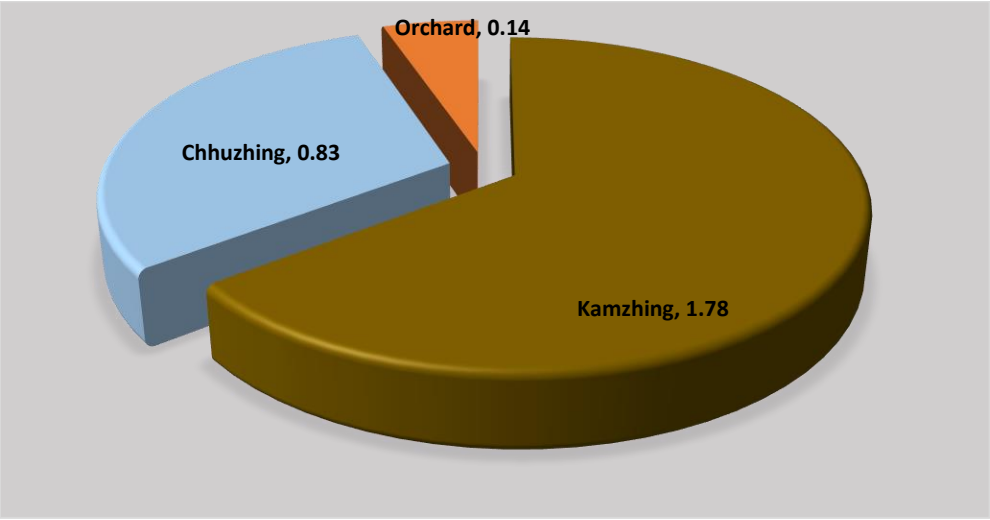

Figure 14 Graphical representation of cultivated agriculture land of Bhutan

Table 7 Percentage of Land use and land cover of Bhutan

Land Cover Class	Sub-class	Area (ha)	Area (%)	Total Area (%)
Forests	Bluepine	101155.06	2.64	**70.77**
	Broadleaf	1763899.46	45.94	
	Chirpine	101537.45	2.64	
	Fir	230983.99	6.02	
	Mixed conifer	519585.68	13.53	
Alpine Scrub	Alpine Scrubs	130097.72	3.39	**3.39**
Shrubs	Shrubs	374032.56	9.74	**9.74**
Meadows	Meadows	96273.61	2.51	**2.51**
Cultivated Agriculture	Chhuzhing	31891.87	0.83	**2.76**
	Kamzhing	68260.64	1.78	
	Orchards	5529.92	0.14	
Built up	Built up	7457.03	0.19	**0.19**
Non Built up	Non Built up	595.89	0.02	**0.02**
Snow and Glacier	Snow and Glacier	205343.63	5.35	**5.35**
Water Bodies	Lake	6252.58	0.16	**0.65**
	River	18923.20	0.49	
Moraines	Moraines	14393.94	0.37	**0.37**
Rocky Outcrops	Rocky Outcrops	119754.16	3.12	**3.12**
Scree	Scree	39701.39	1.03	**1.03**
Landslides	Landslides	3730.22	0.10	**0.10**

Table 8 Relative distribution of land use and land cover by Dzongkhag (%)

Dzongkhag/ LULC Class	Forest	Alpine Scrub	Shrubs	Meadows	Cultivated Agriculture	Built up	Non Built up	Snow and Glacier	Water Bodies	Moraines	Rocky Outcrops	Scree	Landslides
Bumthang	51.79	9.16	12.75	3.76	1.26	0.17		10.82	0.69	0.76	5.63	3.21	
Chhukha	89.26	0.10	3.36	1.41	4.22	0.45	0.02		0.74		0.25		0.19
Dagana	89.14	0.48	3.06	1.32	4.34	0.06			0.93		0.50		0.17
Gasa	19.60	8.17	22.41	3.54	0.15	0.01		22.14	0.74	3.03	16.29	3.91	0.02
Haa	66.67	2.29	15.96	5.03	0.91	0.14		0.21	0.36		7.43	0.98	0.01
Lhuentse	64.79	4.05	9.35	1.15	1.31	0.06		16.75	0.41	0.34	1.49	0.25	0.04
Mongar	91.35	0.02	4.05	0.38	3.41	0.13			0.46				0.19
Paro	52.00	4.28	22.70	9.97	4.26	0.47	0.03	1.49	0.41		2.95	1.44	
P/Gatshel	90.82		4.16	0.01	3.63	0.20	0.05		0.64		0.22		0.27
Punakha	83.63	3.26	5.16	0.44	4.27	0.27		1.99	0.74		0.23		0.01
S/Jongkhar	90.75	0.01	4.70	0.26	2.95	0.10	0.02		0.92		0.09		0.20
Samtse	81.42	0.01	4.35	0.19	11.39	0.24	0.12		1.64		0.16		0.48
Sarpang	89.58	0.04	3.06	0.01	4.90	0.27	0.01		1.81		0.04		0.27
Thimphu	40.04	7.54	22.35	10.31	0.96	0.78	0.05	5.49	0.26	0.42	5.33	6.48	
T/gang	79.15	4.29	7.95	3.24	4.51	0.29		0.09	0.34		0.04		0.11
Tongsa	85.59	4.42	4.65	2.48	1.42	0.27		0.56	0.24		0.28	0.03	0.07
Tsirang	87.50	0.02	2.18	0.09	9.03	0.11			0.68		0.34		0.04
W/phodrang	66.07	4.40	11.65	3.02	1.46	0.14	0.03	6.98	0.50	0.31	4.73	0.71	0.01
T/Yangtse	69.97	3.19	11.47	0.57	2.43	0.05		11.47	0.60		0.25	0.07	0.02
Zhemgang	94.17	0.53	2.69	0.03	1.44	0.05		0.11	0.69		0.12		0.15

Maps of aforementioned statistic by Dzongkhags are available in Atlas of Bhutan, Land Use and Land Cover 2016. Digital data is available at Forest Resources Management Division, Department of Forests and Park Services.

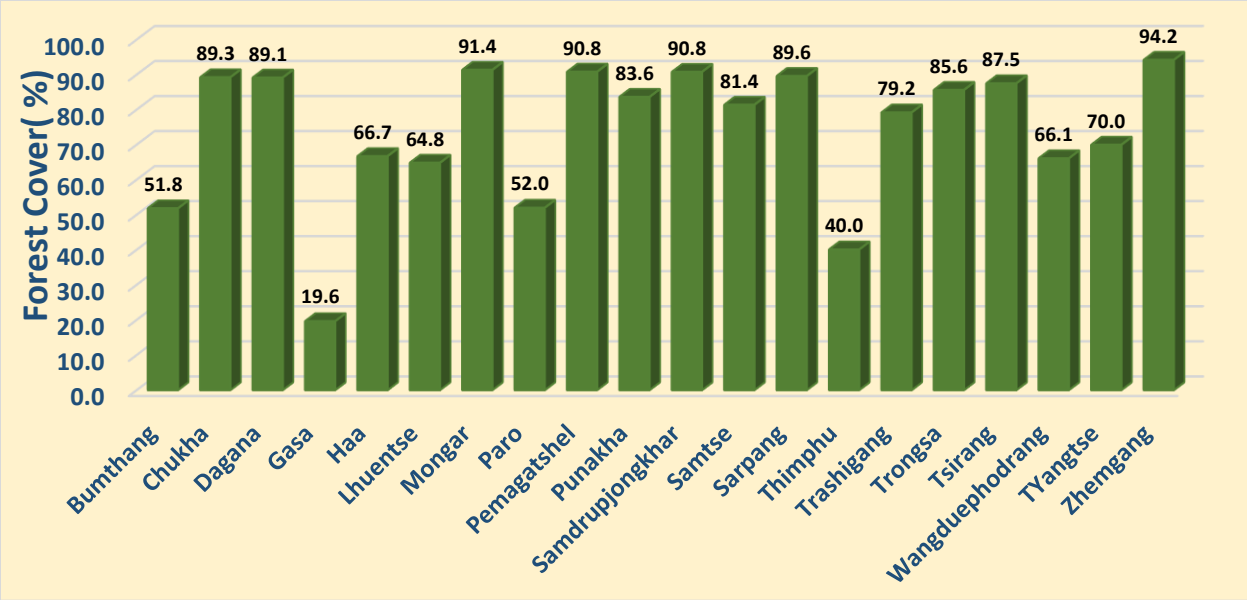

Figure 15 Graphical representation of forest cover by Dzongkhag

Zhemgang Dzongkhang has the highest forest cover with 94.2% while Gasa Dzogkhag has the lowest with 19 %.

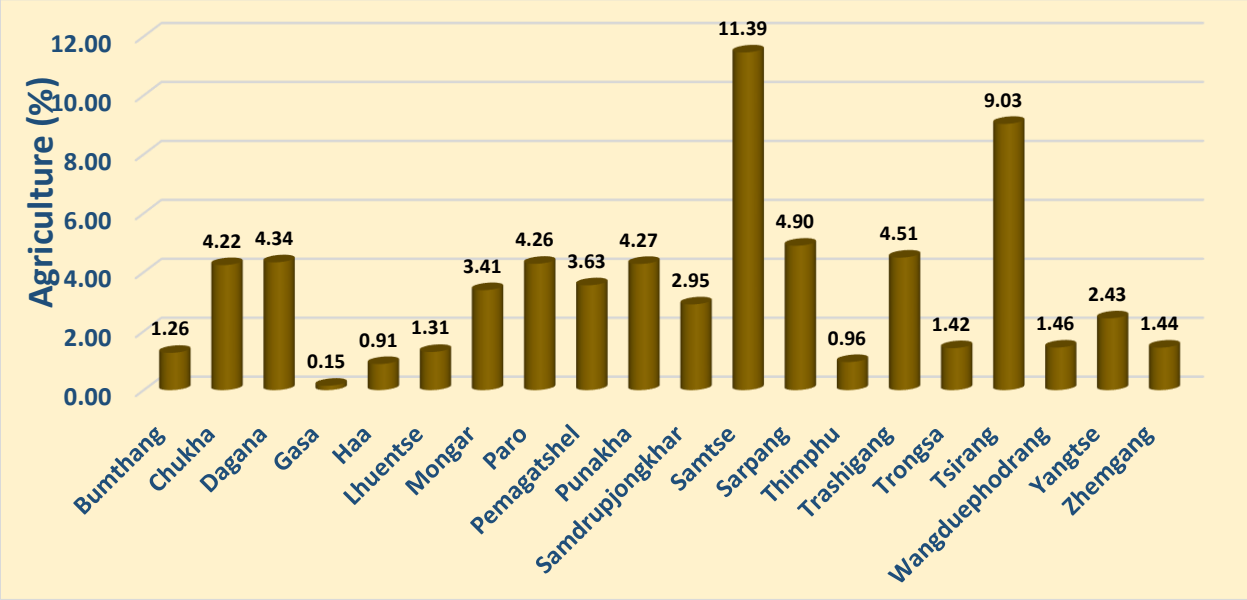

Figure 16 Graphical representation of cultivated agriculture land by Dzongkhag

Samtse Dzongkhag has highest area under agriculture cultivation with 11.39% while Gasa Dzongkhag has the lowest with 0.15%.

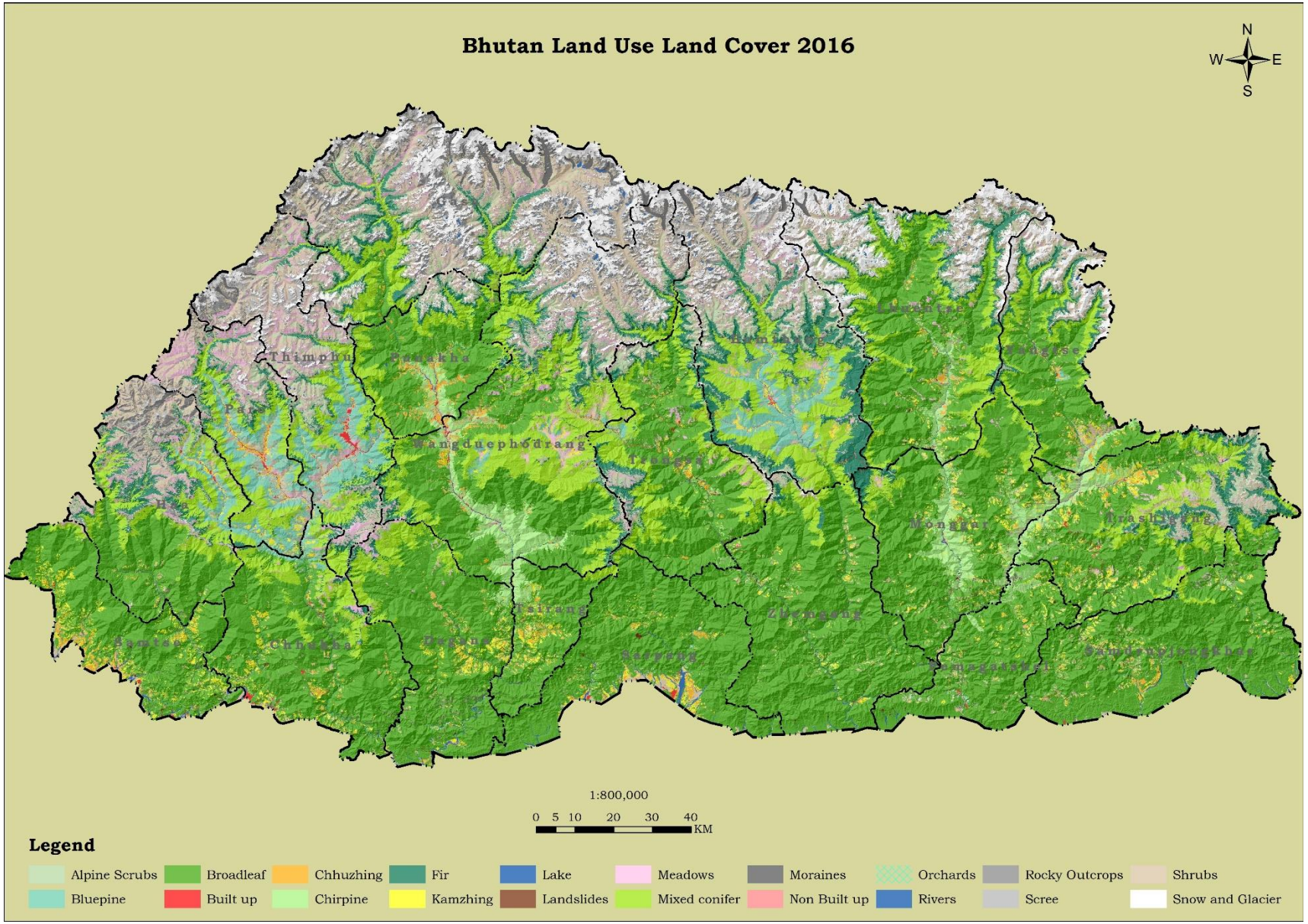

Figure 17 Land Use and Land Cover Map 2016

7. Comparison with LCMP 2010

The current assessment doesn't show significant difference from LCMP 2010. The total forest in LCMP 2010 was 70.46% while in LULC 2016 it shows 70.77%. Cultivated agriculture in LCMP 2010 is 2.93% which is 2.75% in LULC 2016. The only significant difference is observed in snow and glaciers which decreased from 7.46% (LCMP 2010) to 5.35% (LULC 2016). The general minute difference could be due to different in spatial and temporal resolution of the satellite imageries.

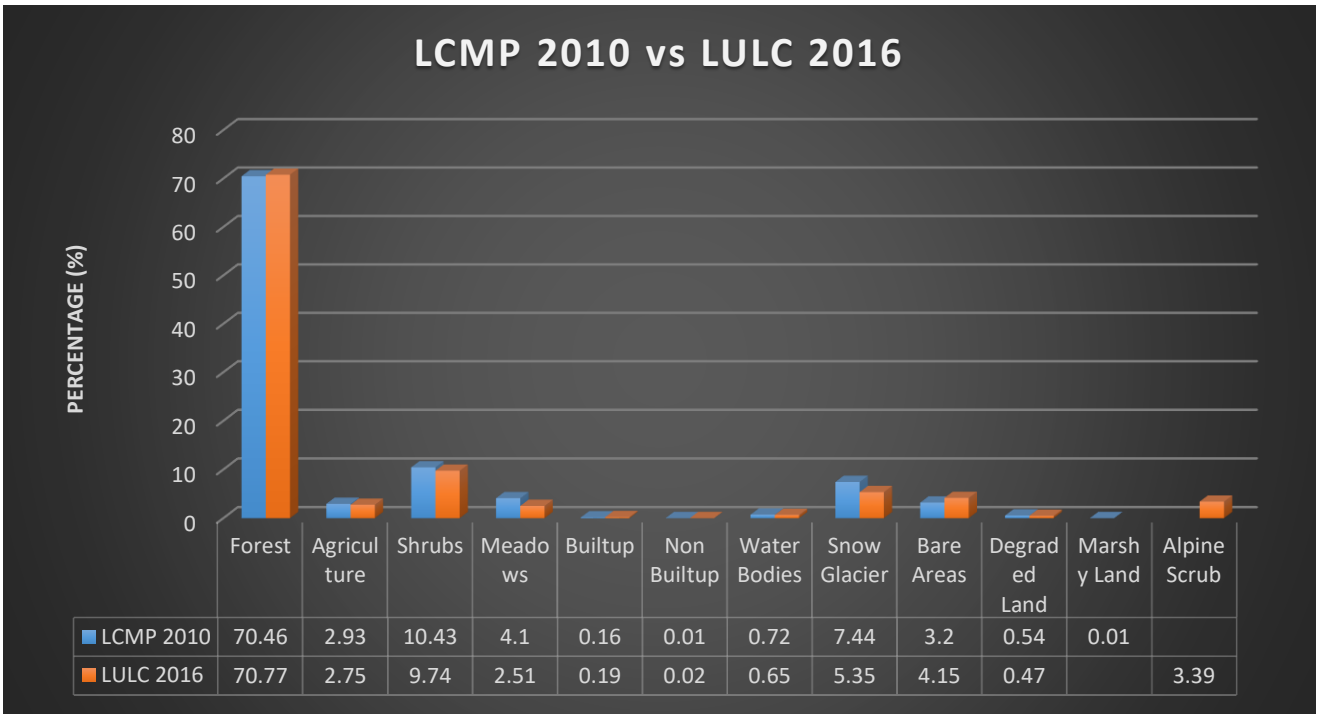

Figure 18 Graphical representation of LCMP 2010 and LULC 2016

8. Constraint and Limitation

- The mountainous topography of Bhutan possesses the challenge for remote sensing due to shadow effects which make it difficult to differentiate and interpret the land cover.
- Satellite imageries suitable for analysis in Bhutan is usually limited to winter season due to cloud cover.
- The imageries from the winter season created some difficulties in differentiating seasonally uncultivated agricultural land from shrubs and meadows.
- The spatial resolution of Landsat 8 (OLI) is 30m which implies that the area of $900m^2$ is minimum mapping unit which is equivalent to one pixel. Due to this medium coarse spatial resolution, detail information for land use classes having area less than $900m^2$ could be generalized. For example, most of the road network were not captured.
- Although the forest definition account both height and area, however in optical remote sensing, height parameter for mapping forest couldn't be considered.
- LULC 2016 assessment accounts only the current land use and land cover type and not the actual registered land category. Therefore, there is high probability that land use and land cover figure is not comparable with figure of National Land Commission and RNR.
- LULC 2016 assessment provides information about the coverage and distribution of land use and land cover for strategic planning and management rather than to identify the actual boundaries and land holding size.

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