National Land Cover Monitoring System of Nepal

GOVERNMENT OF NEPAL
MINISTRY OF FORESTS AND ENVIRONMENT
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Contents

Acronyms and abbreviations

AMSL	Above Mean Sea Level
ARR	Afforestation, Reforestation, And Restoration
CBD	Convention on Biological Diversity
CBFM	Community Based Forest Management
CBS	Central Bureau of Statistics
CEO	Collect Earth Online
CFUG	Community Forest User Group
CTW	Carbon Trade Watch
DoFSC	Department of Forests and Soil Conservation, Nepal
DoA	Department of Agriculture, Nepal
DoF	Department of Forest
EIS	Environmental Impact Statement
EO	Earth observation
EROS	Earth Resources Observing System
ET	Evapotranspiration
FAO	Food and Agriculture Organization of the United Nations
FREL	Forest Reference Emission Level
FRTC	Forest Research and Training Centre
GDP	Gross Domestic Product
GEE	Google Earth Engine
GEOSS	Global Earth Observation System of Systems
GFOI	Global Forest Observations Initiative
GFRA	Global Forest Resource Assessment
GIS	Geographic Information Systems
GLAD	Global Land Analysis and Discovery
HKH	Hindu Kush Himalaya
ICIMOD	International Centre for Integrated Mountain Development
IPCC	Intergovernmental Panel on Climate Change
MEA	Millennium Ecosystem Assessment
MEL	Monitoring, Evaluation and Learning
MoFE	Ministry of Forests and Environment
MRV	Monitoring, reporting and verification
NASA	National Aeronautics and Space Administration
LCCS	Land Cover Classification System
NLCMS	National Land Cover Monitoring System
LULC	Land use and land cover
OWL	Other wooded land
REDD	Reducing emissions from deforestation and forest degradation
RLCMS	Regional Land Cover Monitoring System
RS	Remote Sensing
UMD	University of Maryland
UN	United Nations
UNFCCC	United Nations Framework Convention on Climate Change
UNCED	United Nations Conference on Environment and Development
USAID	U.S. Agency for International Development
USDA	United States Department of Agriculture
USFS	United States Forest Service
WGS	World Geodetic System
WWF	World Wide Fund for Nature

Message from the Honourable Minister

I would like to acknowledge the efforts of the Forest Research and Training Centre (FRTC) in implementing the National Land Cover Monitoring System (NLCMS) and all thecollaborators contributing to the successful completion of the work. On behalf of the Government of Nepal, I am thankful to the International Centre for Integrated Mountain Development (ICIMOD) for providing technical support to develop the land cover monitoring system and the Department of Survey, the Mapping Committee for the comprehensive review, feedback, and endorsement.

Assessment of land cover dynamics is essential for the sustainable management of natural resources, environmental protection, and food security and is required for specific national and international reporting. Considering the importance of land cover for environmental studies, the Nepal government has always sought a land cover monitoring system that produces regular, consistent, and high-quality land cover data using a harmonized classification scheme compatible with the country's needs. The NLCMS achieved annual land cover data from 2000 to 2019 in Nepal. The NLCMS dataset will be useful for national and international reporting, including support to forest management and GHG emissions reduction plans, and to prepare effective ecosystem management plans.

I am confident that FRTC will continue regular update of annual land cover data in coming years efficiently and effectively with the support of ICIMOD and other stakeholders. Finally, I would like to assure that the Ministry of Forests and Environment is committed to institutionalize NLCMS for forestry sector policy, planning and sustainable management of forest resouces. I hope the land cover data will be beneficial to the full extent to all decision-makers, planners, academicians, students and other professionals working in the field of natural resource management.

Thank you.

Ramsahay Prasad Yadav
Minister
Ministry of Forests and Environment

Foreword

Land cover change is a dynamic process. Natural and anthropogenic factors can affect land cover and land use and which is further exaggerated by climate change. Frequent monitoring and assessment of land cover and land use are important for understanding the land cover dynamics and making policies for sustainable management and strategic planning.

The National Land Cover Monitoring System (NLCMS) uses freely available historical satellite imageries on a cloud-based image analysis platform to facilitate annual land cover monitoring that ensures the sustainability of the system. This system will be highly useful for national and international reporting such as Long-Term Strategy (LTS), Nationally Determined Contribution (NDC) to name a few. I am optimistic that the system will be useful for submission to the System of Environmental-Economic Accounting (SEEA) framework. Likewise, the system will be useful for continuous measurement, reporting and verification (MRV) during the implementation of reducing emissions from deforestation and forest degradation (REDD) process. The maps will also be valuable for mapping ecosystems and forest types in Nepal. The system is flexible enough to customize into six land cover classes for Intergovernmental Panel on Climate Change (IPCC) reporting, three land cover classes for Global Forest Resource Assessment (GFRA) reporting, and other international reporting mechanisms as necessary.

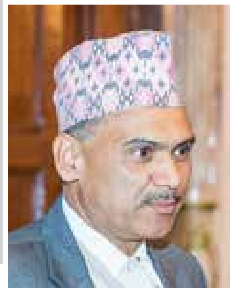
The consistent time series data for two decades will help us understand the changes in different land cover types and conversion trends in the different physiographic regions and at the provincial level. The spatiotemporal pattern of the changes would also provide insights into the effectiveness of current and previous policies and management practices at national and province levels.

I highly appreciate the efforts of the Forest Research and Training Centre (FRTC) in developing the NLCMS and I would like to express my sincere gratitude to the International Centre for Integrated Mountain Development (ICIMOD) and all the collaborators for their support during the development of the NLCMS.

The Ministry of Forests and Environment is confident that the development of the NLCMS to produce annual land cover maps from 2000–2019 is a milestone for Nepal and would contribute significantly to the data demands and data needs. Furthermore, it will be an important national system for the assessment and monitoring of land cover dynamics for the sustainable management of natural resources in Nepal.

Dr. Pem Narayan Kandel
Secretary

Acknowledgments



The Forest Research and Training Centre (FRTC) would like to thank the International Centre for Integrated Mountain Development (ICIMOD) for providing technical support for the development of the National Land Cover Monitoring System (NLCMS) of Nepal through its SERVIR Hindu Kush Himalaya (SERVIR-HKH) Initiative implemented in partnership with the National Aeronautics and Space Administration (NASA) and the United States Agency for International Development (USAID).The FRTC also highly appreciate the support received from the co-development partners: SilvaCarbon, Global Land Analysis and Discovery (GLAD) group at the University of Maryland, and the US Forest Service.

The FRTC sincerely thanks the different national agencies namely the Ministry of Forests and Environment (MoFE), the Department of Forests and Soil Conservation, the Survey Department, the Department of Agriculture, the Central Bureau of Statistics and the Central Department of Geography for their contribution in finalizing the land cover legends and their overall feedback on the final land cover maps.

My sincere thanks goes to the Technical sub-committee, Mapping Committee of Survey Department for endorsing the specification to prepare the NLCMS. I am thankful to the Senior Management Team, MoFE for the validation of the NLCMS and its final land cover products.

In particular, I appreciate the efforts of the following individuals who, in their various capacities have contributed for the successful development of the NLCMS.

Technical Team (GoN): Amul Kumar Acharya, Ananda Khadka, Bimal Kumar Acharya, Milan Dhungana, Raja Ram Aryal, Sangita Ahakya, and Yam Prasad Pokharel

Technical Team (SERVIR): Ate Poortinga, Bikram Shakya, Birendra Bajracharya, David Saah, Kabir Uddin, Karis Tenneson, Kiran Shakya, W. Lee Ellenburg, Mir A. Matin, Nishanta Khanal, Peter Potapov, Sajana Maharjan, Sudip Pradhan and Timothy Mayer

Data Collection Team: Amul Kumar Acharya, Ananda Khadka, Apsara Poudel, Kabir Uddin, Prabesh Shrestha, Raja Ram Aryal, Sajana Maharjan, and Sangita Shakya,

Field Validation Team: Amul Kumar Acharya, Anand Khadka, Apsara Paudel, Bhisma Ghimire, Bimal Kumar Acharya, Birendra Bajracharya, Kabir Uddin, Nishanta Khanal, Prabesh Shrestha, Sangita Shakya, Tirtha Raj Baral, and Yam Prasad Pokharel.

Report Review and Production Team: Amul Kumar Acharya, Ananda Khadka, Bimal Kumar Acharya, Bishnu Prasad Dhakal, Dharma Maharjan, Dhirendra Kumar Pradhan, Gauri Shankar Dangol, Milan Dhungana, Rachana Chettri, Raj Kumar Giri, Raja Ram Aryal, Shiva Khanal, Utsav Maden, and Yam Prasad Pokharel.

Finally, I would like to thank all contributors who were directly or indirectly involved in developing the NLCMS of Nepal.

Yam Prasad Pokharel
Director General

Executive summary

The National Land Cover Monitoring System (NLCMS) has been developed to provide annual land cover maps by using consistent remote sensing datasets. This is an operational and flexible system to produce land cover maps from 2000 to 2019. This report provides comprehensive information on land cover statistics and land cover change analysis of 2000 and 2019 at the national, province level and at physiographic regions. These types of information are important for national and international reporting, strategic planning, research, and development in forestry and other related sectors.

Land cover maps have been prepared by using Landsat 5, 7, and 8 images and other additional layers such as digital elevation model (DEM), tree canopy height, and tree canopy cover are provided by the Global Land Analysis and Discovery lab (GLAD) of the University of Maryland (UMD). Similarly, the glaciers and glacial lakes data were generated by ICIMOD and built-up area layers and nighttime light data layers were sourced from OpenStreetMap (OSM) and National Oceanic and Atmospheric Administration (NOAA) respectively.

The land cover of Nepal was mapped based on the approach and methodology used in the Regional Land Cover Monitoring System developed under ICIMOD's SERVIR-HKH Initiative and uses a co-development approach with relevant stakeholders. The NLCMS development process includes eight steps namely; (i) defining the land cover classification schemes and typology, (ii) collecting training samples using Collect Earth, (iii) preparation of annual composites, (iv) selection of additional thematic data, creation of image indices and covariates, (v) utilization of supervised machine learning algorithms and creation of the land cover primitives, primitives evaluation and smoothing, (vi) input of annual tree canopy cover and height, (vii) construction of customized land cover maps and (viii) validation of the land cover maps and assessment of accuracy.

Eleven land cover classes were identified for the country. The steps such as image pre-processing, preparation of covariates, utilization of supervised machine learning algorithms for primitive generation, temporal smoothing, and assemblage were performed in Google Earth Engine (GEE) computational platform.

The total forest cover of the country is 41.69% (6166766 ha) in 2019 whereas, in 2000, it is 39.99% (5915518 ha). Cropland and grassland are other major land covers of the country in both years with 24.21%, and 13.27% respectively in 2019 and, 26.31%, and 13.95% respectively in 2000. About 3.62 % (535179 ha) of the total area of the country is covered by other wooded land (OWL) in 2019 while in 2000, it was about 3.57% (527915 ha). Snow, bare rock, glacier, riverbed, built-up, water bodies, and bare soil occupy less than 18% of the country in both years.

Land cover statistics at the Province level in 2000 and 2019 showed variations across Provinces. Forest cover is predominant in all the Provinces except in Madhesh province. Apart from Madhesh province and Karnali Province, forest cover is increasing from 2000 to 2019. The area covered by OWL has increased tremendously in Madhesh province and slightly in Lumbini and Sudurpaschim Provinces and OWL has decreased in Province No. 1, Bagmati, Gandaki, and Karnali Provinces. The built-up area has increased in all Provinces. In contrast, cropland has decreased in all Provinces.

Cropland is a dominant land cover in the Terai and forests in the Siwalik, Middle Mountain, and High Mountain physiographic regions. In contrast, grassland has dominant land cover in the High Himal physiographic region. This trend remained the same in 2000 and 2019 for all physiographic

regions. Forest cover has increased in the Terai, Siwalik, and Middle Mountain region whereas it has decreased in High Mountain and High Himal from 2000 to 2019. In addition, OWL has increased in Terai and Siwalik region whereas it has decreased in Middle Mountain, High Mountain, and High Himal from 2000 to 2019. Cropland is decreasing in all the physiographic regions. In contrast, built-up is increased gradually in all regions. Grassland is decreased in all physiographic regions except High Mountain.

The change analysis between 2000 and 2019 land cover data showed that forest has increased by 1.70% from 2000 to 2019 whereas cropland and grassland have decreased by 2.10% and 0.68% respectively. The built-up area has increased by 0.36%. The assessment showed that the forest has converted to OWL, cropland, and grassland. Whereas, OWL mainly has changed to the forest, whereas a large portion of cropland has turned to forest, OWL, built-up, and grassland from 2000 to 2019. The overall classification accuracy is 84.80% and the overall kappa statistic is 0.73.

Though the land cover mapping methodologies are always changing and improving, the current NLCMS has been designed in open platform architecture allowing flexibility to adopt emerging technologies for sustained implementation by the end-users.

1. Introduction

Land cover assessment and consideration of its dynamics can underpin sustainable natural resources management, environmental protection, and food security (Andrew et al., 2014; GCOS, 2003; GEOSS, 2005; Herold et al., 2006, 2008; Lambin et al., 2001). Land cover maps provide information on observed biophysical cover on the Earth's surface that can be used as a geographical reference in different disciplines such as geography, ecology, geology, forestry, land policy, and planning (FAO, 2016).

Social, economic, and cultural utility (Turner et al., 1996) along with ecosystem functions (Defries et al., 2009) of land cover are reflected as land use pattern. Land use mostly includes the administration and modification of the natural environment. The alteration of the Earth's surface by anthropogenic activities is usually known as land use and land cover change. The continuous change in land use pattern to fulfill livelihood and other essential needs alters the land cover (Foley et al., 2005). Therefore, land cover change is a dynamic process in which anthropogenic and natural activities (Lambin et al., 2003) influence biophysical processes (Li & Shao, 2014). There are several direct and indirect drivers of land use and land cover (LULC) change such as deforestation, reforestation, infrastructure development, mining, climate change, and migration (Veldkamp et al., 2001). For instance, conversion of natural ecosystems for agricultural practices has been a primary factor behind land use and land cover change (Ramankutty et al., 1999).

Timely, comprehensive and accurate information about land cover and change dynamics plays an indispensable role in policy development, planning, management, and other data driven decisions in most sectors (Lambin et al., 2001; Poortinga et al., 2018; Turner et al., 1995). Characterizing and mapping land cover is essential for planning and managing natural resources (e.g., development, conservation), environmental modelling, and evaluating the status and transition of ecosystems such as forest harvest (Cohen et al., 2010; Jin et al., 2005; Kennedy et al., 2010; Zhu et al., 2012), glacial retreat (Berthier et al., 2007; Bolch, 2007; Burns et al., 2014; Wei et al., 2014), urban expansion (Song et al., 2016; Weng, 2001; Yang et al., 2003), wildfire (Schröder et al., 2013; Turner et al., 1994), flooding, and drought (Asner et al., 2010; Jeyaseelan, 2003; Thomas et al., 2011).

Unrestricted availability of Earth observation data with global coverage and the emerging analytical tools and techniques offer a unprecedented capability for monitoring global land cover change scenarios in a cost-efficient manner. The advancement in the spatial, temporal and spectral resolution of satellite data combined with open access, rapid increase in computing power and cloud based systems with significant reduction in associated costs in the last decade, have increasingly enabled users to process data and develop land cover products without significant investments in computing infrastructure (Gorelick et al., 2017; C. Yang et al., 2017).

1.1 Land cover mapping in Nepal

Nepal is among the top ten fastest urbanizing countries (UNDESA, 2014). Growth in infrastructures and superstructures could therefore be considered an important element of land cover change in Nepal (Ishtiaque et al., 2017). In the past, factors like grazing, shifting cultivation, illegal/selective logging, flooding and urbanization, have been revealed as major drivers of land cover change in Nepal (Paudel et al., 2016).

Nepal has a long history of preparing national land cover maps, especially the national forest cover map for providing baseline information required for national and international reporting. The first attempts at national-level forest inventory were carried out in between 1963 and 1967 (FRS, 1967). Visual interpretation of aerial photographs taken in 1953–1958 and 1963–1964, mapping, and field inventory were used to produce the map. The Land Resource Mapping Project (LRMP) carried out the first detailed land system mapping in 1986 and generated several datasets (geology, land system, land utilization, and land capability) using aerial photographs from 1978/79 at a scale of 1:50,000 (LRMP, 1986). Similarly, the second national forest inventory was started in the early 1990s and completed in 1998 with a base year of 1994 which produced forest cover maps using Landsat satellite imagery, aerial photographs, and field data. After a long gap, the Department of Forest (DoF) produced a forest cover change map of 20 districts of the Terai physiographic region of Nepal using Landsat satellite imageries and ground verification (DoF, 2005).

The SD produced a new series of TBMs between 1992 and 2001 at the scale of 1:25,000 (for the Terai and middle mountains) and the scale of 1:50,000 (for the higher mountains and Himalayas) covering the entire country in paper print, and they subsequently converted all those maps into digital form by GIS technology and made they available to the users as National Topographical Database (NTDB).

Moreover, the Nepal government's Department of Survey prepared and published a topographic base maps of Nepal between 1992 and 2001 at the scale of 1:25000 for Terai & Middle Mountain and the scale of 1:50000 for the High Mountain and High Himal (Wagle and Acharya, 2020). The International Centre for Integrated Mountain Development (ICIMOD) developed national-level detailed land cover maps of 1990, 2000, and 2010 using Landsat TM 30m resolution satellite imagery to study decadal changes (Uddin et al., 2015). The latest Forest Resource Assessment (FRA) used high-resolution RapidEye images to prepare a wall-to-wall forest cover map (DFRS, 2015).

Recently, Nepal prepared a National Forest Reference level for REDD implementation using Landsat data for 2000 and 2010 (MoFSC, 2016). None of the land cover products from the aforementioned studies are comparable due to inconsistencies in the satellite data and the methodologies used for land cover classification. As a party to the United Nations Framework Conventionon Climate Change (UNFCCC), Nepal needs to prepare a Land Use and Land Cover (LULC) guideline of the IPCC for estimating GHG emissions or removals and reducing uncertainties as far as possible (GFOI, 2013; IPCC, 2006). Further, the GoN (2014) conducted a comprehensive inventory of ecosystems and species as well as update the existing information on ecosystems in 2017 and identified Forest Research and Training Centre (the then Department of Forest Research and Survey) as the main implementing agency. Land cover will be the first data layer for ecosystem mapping. Nepal must have a robust land cover monitoring system to fulfill both national and international data needs.

1.2 Objectives of the National Land Cover Monitoring System of Nepal

The main objective of the National Land Cover Monitoring System (NLCMS) is to generate yearly land cover maps from 2000 to 2019 of Nepal using consistent satellite data and methodology. The specific objectives are as follows:

a) Analysis of land cover conversion pattern.

b) Preparation of land cover change matrix.

c) Estimate the land cover area of the country.

2. The NLCMS approach

The land cover mapping process for Nepal is based on the approach and methodology developed for the Regional Land Cover Mapping System (RLCMS). The RLCMS, developed under ICIMOD's SERVIR-HKH Initiative followed a co-development process through stakeholder engagement. Engagement activities include regional and national consultations, online questionnaire surveys, and regional and national mapping workshops that were conducted during the last five years in the lower Mekong and the Hindu Kush Himalaya (HKH) region. Based on suggestions from stakeholders, the RLCMS considered the following design criteria to ensure its alignments with regional and national needs:

Flexibility

- The system uses land cover "primitives" or continuous layers of biophysical attributes (e.g., forest cover) that can be swapped for the most state-of-the-art product available at any time.
- The system accommodates land cover typologies as per country requirements.

Consistency

- Every country has access to the same set of primitives and assembly systems with varying assembly logic rule sets to accommodate regionally varying land cover definitions.

Based on remotely sensed data

- The system is data-driven with access to big geo datasets provided by novel cloud computing tools. Explicit quantification of uncertainty Monte-Carlo methods incorporate uncertainty from primitives to provide pixel- based estimates of land cover uncertainty.
- Traditional land cover map assessment methods, such as error matrices, are calculated on the final land cover assemblage product.

Explicit quantification of uncertainty

- Monte-Carlo methods incorporate uncertainty from primitives to provide pixel-based estimates of land cover uncertainty.
- Traditional land cover map assessment methods, such as error matrices, are calculated on the final land cover assemblage product.

Capacity building

- The collaborative nature of the system facilitates information and technology exchange.
- Free and broadly accessible tools and public data are used wherever possible.

The RLCMS is built on the Google Earth Engine (GEE) computational platform. The GEE is an online service that applies cloud computing and storage frameworks to geospatial datasets. The GEE archive contains a large volume of Earth observation data. The platform enables scientists to perform calculations on large data series in parallel. The RLCMS was built based on Landsat images to produce land cover at 30m spatial resolution based on the following criteria for data selection:

- Defining spatial and temporal data requirements
- Data should be free to ensure sustainability

Table 1: **Launch and operational phases of different satellite images**

	GOES	MODIS	Landsat	Sentinel	SPOT	IKONOS	Planet Labs
Spectral resolution	5	7	9	13	5	4	3
Spatial resolution	4.6km x 4.2km	250m-1km	30m	10, 20, 60m	10m, 20m, 1.5km	1m, 4m	5m
Temporal resolution	Hourly	1-2 days	16 days	5 days	26 days (S1-7), 1day (S4-5)	3-5 days	Daily
Historical archive	1975-present	1999-present	1972-present	2014-present	1986-present	2000-present	2013-present
Access	**Free**	**Free**	**Free**	**Free**	**Charges apply**	**Charges apply**	**Charges apply**

- Produced consistently to facilitate annual monitoring
- Moderate resolution useful for national-level assessment
- Historical data availability for longer-term analysis

Table 1 lists available open-source and commercial satellite imageries that are used for classification of land cover. Landsat data were used to generate NLCMS as it requires access to historical data archive.

2.1 Technical collaboration

The NLCMS is the customized form of the RLCMS. The RLCMS is a collaborative development. The modular approach of the RLCMS provides flexibility for broader collaboration. The RLCMS has been further customized as the National Land Cover Monitoring System (NLCMS) and rolled out in Afghanistan, Nepal, Bangladesh and Myanmar to cater to country-specific needs. SERVIR-Mekong led by the Asian Disaster Preparedness Center (ADPC), and SERVIR-HKH led by ICIMOD, are the regional hubs of SERVIR responsible for implementing the system with regional and country partners in the lower Mekong and HKH regions. The National Aeronautics and Space Administration (NASA) and United States Forest Service (USFS) provided technical assistance for developing the algorithms and implementing them in GEE. NASA is collaborating with FAO and facilitating the conversion with FAO for an online reference data collection system called Collect Earth Online (CEO) to implement the RLCMS framework into its System for Earth Observation Data Access, Processing and Analysis for Land Monitoring (SEPAL). The USAID-funded SilvaCarbon project supported organization of training and workshops. Besides these, additional collaboration took place on individual primitive levels. The University of Maryland collaborated in customizing a tree cover algorithm for producing tree cover and tree height.

Figure 1: **Flowchart of overall method**

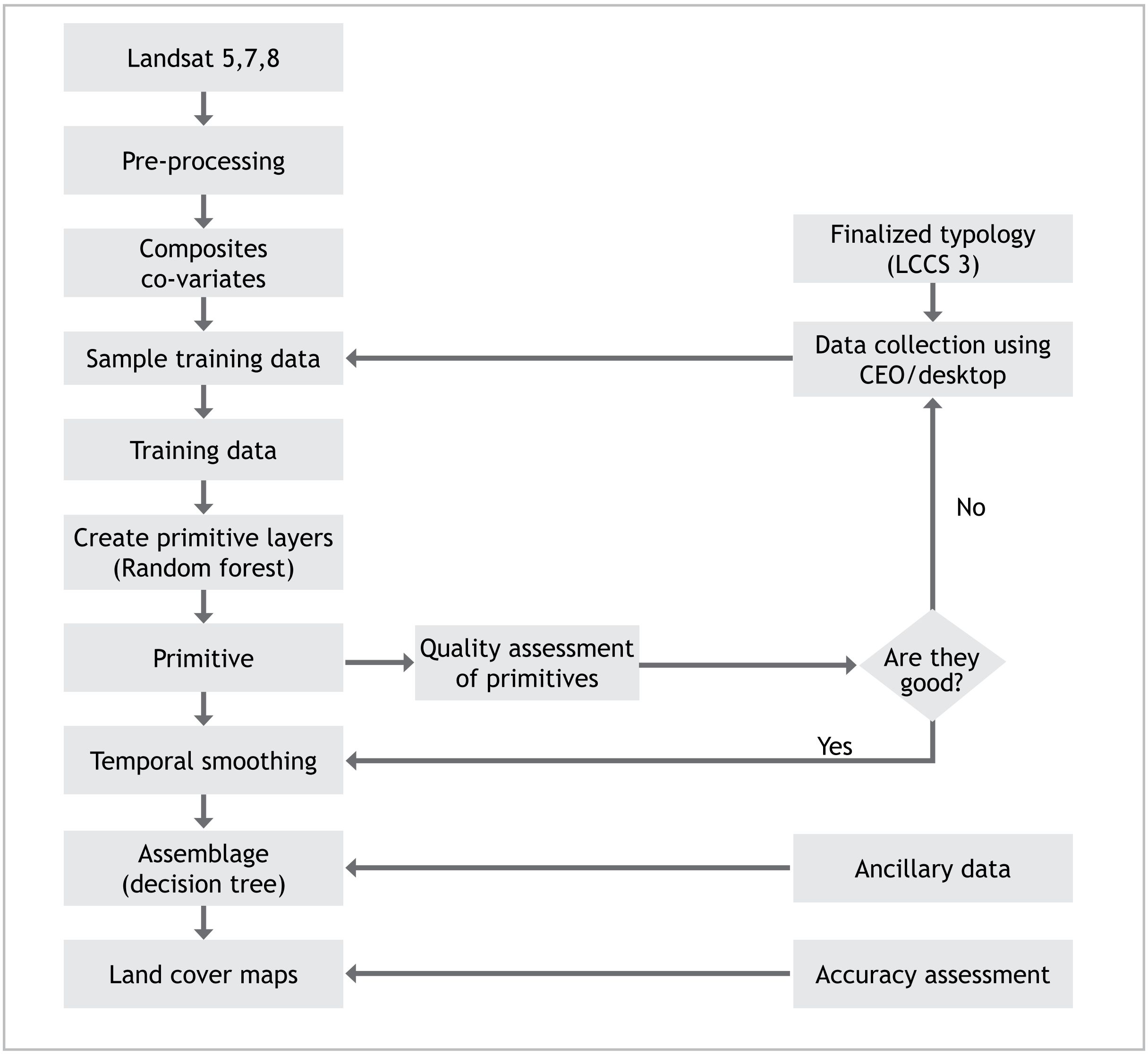


Figure 2: **At the workshop on National Land Cover Classification System for Nepal**

Table 2: **Land cover classes and definition**

Main land cover class	Description	IPCC land cover class
Forest	Land spanning more than 0.5 ha with trees higher than 5 m and a canopy cover of more than 10%, or trees able to reach these thresholds in situ. It does not include land that is predominantly under agricultural or urban land use.	Forest
Other wooded land (OWL)	Land not classified as forest spanning more than 0.5 ha, having at least 20 m width and a tree canopy cover of trees between 5% and 10%. or The canopy cover of trees less than 5% but the combined cover of shrubs, bushes and trees more than 10%; includes area of shrubs and bushes where no trees are present.	Forest
Grassland	Areas covered by herbaceous vegetation with cover ranging from Closed to Open (15–100%). This category includes rangeland and pasture that is not considered cropland.	Grassland
Cropland	This category includes arable and tillage land, and agroforestry systems where vegetation falls below the thresholds used for the forest land category, consistent with the selection of national definitions.	Cropland
Built-up area	Built-up areas refer to artificial structures such as towns, villages, industrial areas, airports, etc.	Settlements
Water body	Rivers are natural flowing water bodies and typically have elongated shapes. Lakes and ponds are perennial standing water bodies.	Water body
Riverbed	A tract of land without vegetation surrounded by the waters of an ocean, lake, or stream; it usually includes any accretion in a river course.	Water body
Bare soil	A soil surface devoid of any plant material.	Other
Bare rock	Non-vegetated areas with a rock surface.	Other
Snow	This class describes perennial snow (persistence > 9 months per year).	Other
Glacier	Perennial ice in movement.	Other

3. Methodology

The general methodology of the NLCMS includes eight major steps: 1) defining the land cover classification schemes and land cover typology, collecting land cover training samples, selection of Landsat imagery, image correction, preparation of annual composites, selection of additional thematic data, creation of image indices and covariates to make input layers for machine learning, utilization of supervised machine learning algorithms and creation of land cover primitives, primitives evaluation and smoothing, 6) input of annual tree canopy cover and height, 7) construction of customized land cover maps by modifying the assemblage logic using a decision tree, 8) validation of the land cover maps and assessment of accuracy. A systematic flowchart showing the method of the NLCMS development is shown in Figure 1 and described below in detail:

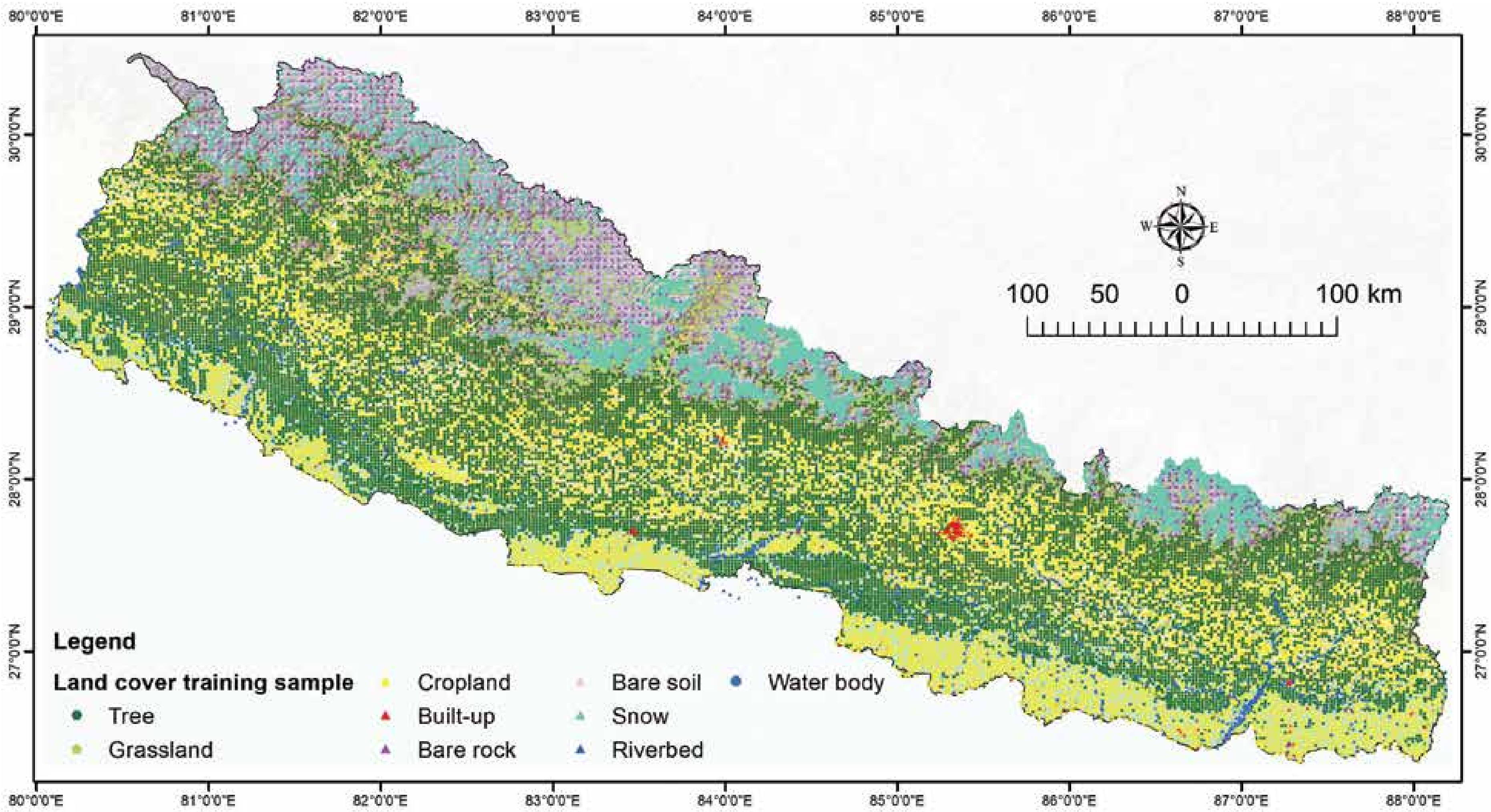
3.1 Establish land cover typology

The first step in developing land cover maps is defining the typology. The NLCMS requires robust land cover typologies and definitions. These are important for determining the map assemblage and reference data collection. A classification system, or typology, should be clear, precise and based on objective criteria (Bajracharya et al., 2010). To define the typology of the NLCMS, Nepal, a workshop was conducted by the FRTC with participants from various departments such as the Ministry of Forests and Environment, the Department of Agriculture, the Department of Forest and Soil Conservation, the Central Bureau of Statistics and the Central Department of Geography, Survey Department (Figure 2). The participants agreed on 11 land cover classes (forest, cropland, built-up area, glacier, snow, water body, riverbed, bare soil, bare rock, grassland, other wooded land) for the country. Nepal has to report to the Intergovernmental Panel on Climate Change (IPCC) with the six land use classes for REDD and Global Forest Resource Assessment (GFRA) purposes. Therefore, these typologies are very suitable for representing the present land cover of Nepal in the wall-to-wall maps. The Land Cover Classification System (LCCS) Software version 3 developed by FAO was used to define each class. The list of land cover classes with their definitions is provided in Table 2.

3.2 Collecting land cover training samples

Quality-assured reference data is key for the development of the NLCMS and assessment of the results. A total of 36,843 reference samples were collected from the 2 x 2 km grid spread over the entire country as shown in Figure 3 using Collect Earth desktop software. The quality of those points were rechecked thoroughly using high-resolution satellite imageries, and differential indices of vegetation, water and snow. Thereafter, those points that were not considered quality reference points for the particular land cover typology assigned previously were removed. Additional reference data were collected from high-resolution satellite images using the Collect Earth Online (CEO) platform. These data were divided into two lots: i) primitive generation and ii) accuracy assessment of final land cover maps to produce a confusion/error matrix.

Figure 3: **Distribution of training samples**



3.3 Image preprocessing and preparation of co-variates

Landsat 5, 7, and 8 images were used for land cover classification. Various preprocessing steps such as cloud masking, shadow masking, BRDF, and topographic correction were performed to reduce distortion effects (Young et al., 2017). Pixels with cloud and cloud shadows were removed in cloud and shadow masking respectively. Clouds were masked using a pixel-qa band and the Google cloudScore algorithm. Google's cloudScore algorithm uses the spectral and thermal properties of clouds to identify and remove pixels with cloud cover from the imagery. The algorithm identifies pixels that are bright and cold, then compares them to the spectral properties of snow. The snowscore was also calculated using the Normalized Difference Snow Index (NDSI) to prevent snow from being masked. The algorithm calculates scaled cloud scores for the blue, all visible, near-infrared, and shortwave infrared bands and then takes the minimum. The algorithm was described by Chastain et al. (2019).

To remove cloud shadows, we used the Temporal Dark Outlier Mask (TDOM) algorithm (Housman et al., in review), which identifies pixels that are dark in the infrared bands but are found to not always be dark in past and/or future observations. This is done by finding statistical outliers with respect to the sum of the infrared bands. Next, dark pixels were identified by using the sum of the infrared bands (NIR, SWIR1, and SWIR2). The pixel quality attributes generated from the CFMask, C code based on the Function of Mask (Fmask) algorithm (pixel-qa band) were also used for shadow masking. The nadir view angles of the Landsat satellites cause directional reflection on the surface, which can be described by the bidirectional reflectance distribution function (BRDF) (Roy et al., 2016, 2017; Lucht et al., 2000). BRDF correction involves correcting differences in illumination between images. This was necessary to improve image quality.

Topographic correction for Landsat images is necessary for study areas which exhibit mountainous topographic characteristics such as slope and aspect, as they can cause variations in spectral radiance within a particular land cover (Vanonckelen et al., 2013; Moreira et al., 2014). The Modified Sun-Canopy-Sensor Topographic Correction method was followed, as explained by Soenen et al. (2005). This algorithm uses a modified sun-canopy-sensor (SCS) model to account for diffuse radiation.

Projection System: Lambert Conformal Conic

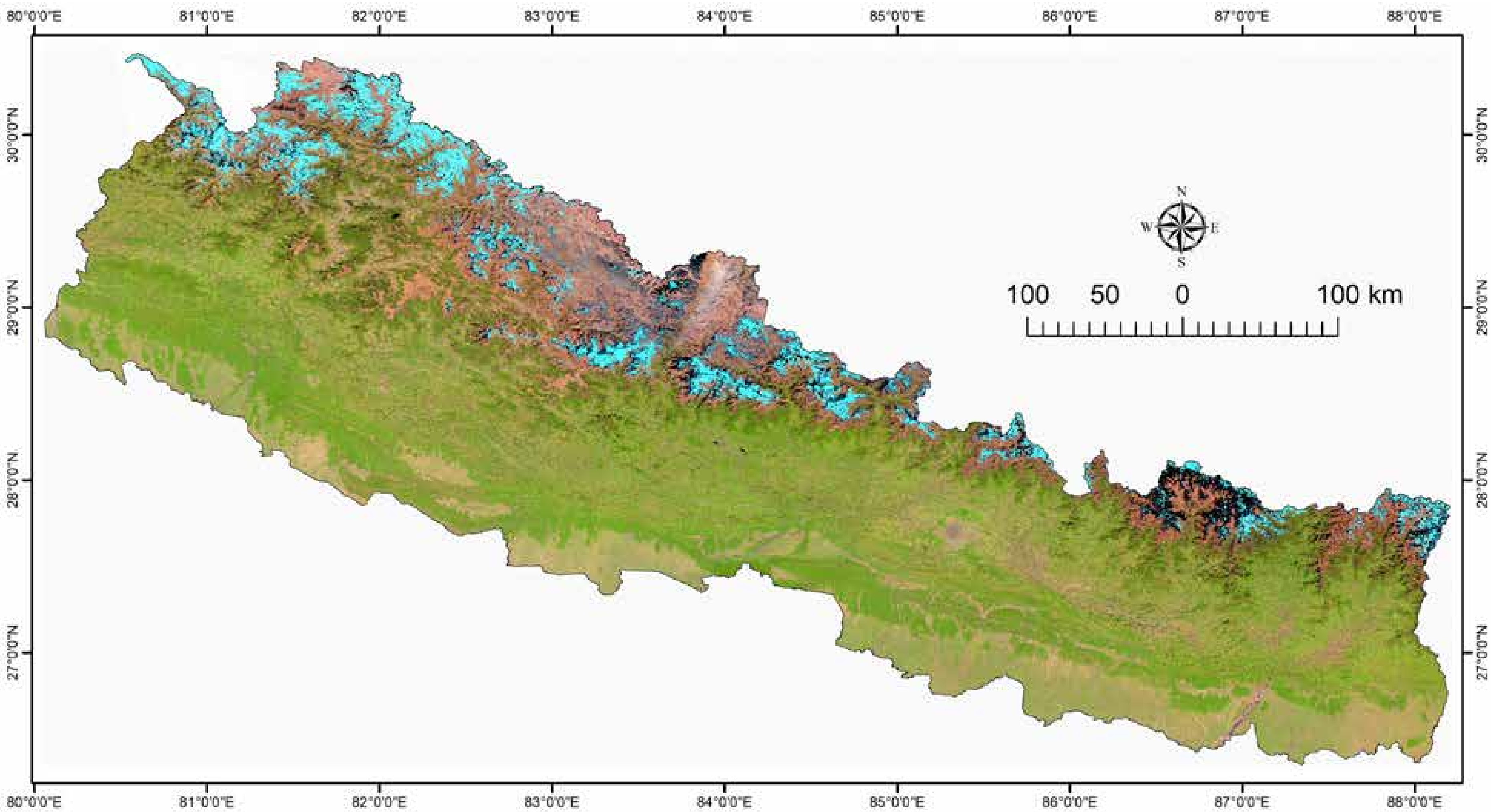
Standard Parallel 1	27° 00'00" N
Latitude Of Origin	28° 22'40.92" N
Standard Parallel 2	29° 45'00" N
Central Meridian	84° 00'00.00"E
Scale Factor	1.0000
Spheriod	Everest 1830

After preprocessing, composites for every year (2000–2019) were prepared by consolidating all available images for each year into a single image (Figure 4). Every single image (composite) represented a particular year and was used to prepare the land cover map for that year. Each pixel value of the composite is a medoid, the observed value closest to the median. Each composite consists of 24 bands. It includes Landsat bands such as red, green, blue, NIR, SWIR1 and SWIR2, the percentile of these bands, percentile of indices such as NDVI, snow index, and urban index. A composite for 2012 was not prepared due to Landsat 7 ETM+ SLC (Scan Line Corrector) of images (Chen et al., 2011)

3.4 Primitive generation and smoothing

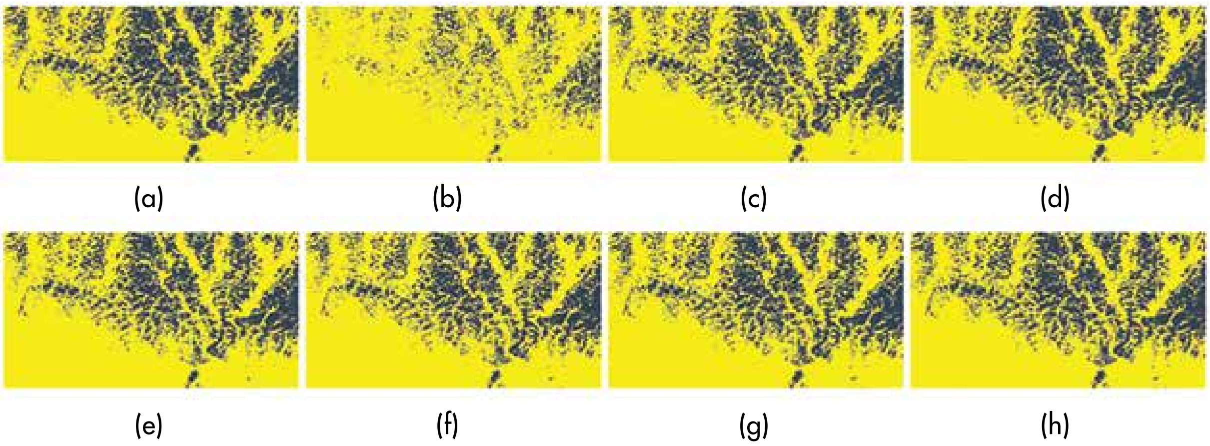
Primitives are building blocks for generating land cover maps (Saah et al., 2020). They are mappable biophysical elements that can be used alone or in combination to define a class. It is a probability layer, which means each pixel of the layer represents the probability of particular biophysical features. This approach has made the system highly flexible as land cover classification can be done based on the adopted definition of the classes, which might vary with multiple stakeholders.

Figure 4: **A true color composite of the Landsat image used for the land cover mapping**



Since there are 76 covariates, it is important to understand which covariates contribute to better separating particular primitives from others. Temporal Smoothing Algorithms proposed by Khanal et al. (2020) were implemented in R RStudio Software (R Core Team, 2020) to prioritize covariates for generating each primitive layer (Saah et al., 2020). The order of covariates was different for each primitive. Using this information and a Random Forest classifier, primitives were generated. Initially, nine primitives were generated through this process. They were bare rock, bare soil, built-up area, cropland, tree, water, snow, grassland, and riverbed.

Figure 5: **Demonstration of forest (green) and other land cover (yellow) from 2013 to 2016 in the southern part of the study region**



(a–d) display un-smoothened results for 2013, 2014, 2015, and 2016 respectively. In the same way, (e–h) show smoothened results for 2013, 2014, 2015, and 2016 respectively. A considerable improvement can be seen in 2014. These are the final results generated from the best primitive set, i.e., picking the best primitives after applying different algorithms on each primitive.

3.4.1 Temporal smoothing

Land cover data is sometimes inconsistent when compared across different years due to noise and misclassification in data for some years. A temporal smoothing technique was used to reduce these noises and make the data temporally consistent. Temporal smoothing was applied for some primitives such as tree, built-up area, riverbed, and grassland (Figure 5). A Fourier Smoothing algorithm was used in this process (Khanal et al., 2020).

3.5 Input of annual tree cover height from UMD GLAD

Global Land Analysis and Discovery Lab (GLAD) at the University of Maryland has been developing tree canopy cover and height at a global scale. GLAD global initiation and algorithm were customized and improved through collaboration between SERVIR to produce annual dynamics of woody vegetation structure and primary forest extent. The products were consistent at the regional level and provided at a spatial resolution appropriate for the national analysis. For the NLCMS, we used Potapov et al. 2020 developed the tree canopy cover and tree cover height data as input to land cover mapping. The tree canopy height represents the median height of the top of the tree canopy above the ground. The map value represents canopy height in metres for each year. The regional tree cover and height model were calibrated using tropical airborne lidar data and applied annually.

3.6 Land cover assemblage

All the generated primitives and other additional layers such as DEM, tree canopy height, and tree canopy cover provided by Global Land Analysis and Discovery (GLAD) and the University of Maryland (UMD), glacier and glacial lake data generated by ICIMOD, built-up layers of the open street map (OSM), and night light were also used as external primitives in the assemblage. During the assemblage, a decision tree classifier was used to classify each pixel and produce the land cover map. The primitive and assemblage process is shown in Figure 6.

3.7 Accuracy assessment

In the context of remote sensing-based land cover classification, the accuracy assessment process can be defined as an evaluation of agreement between reference samples and the classified image. Classification error occurs when a pixel (or feature) belonging to one category is assigned to another category. Accuracy assessment can be done using qualitative methods through visual interpretation and quantitative evaluation based on statistical methods. For the quantitative accuracy assessment, an error matrix method is widely used. This is a statistical method in which the assessment is performed by comparing the classification results to the set of reference data. For the land cover map of Nepal, the accuracy assessment was done for land cover data from the most recent year (2019). For validation,independent reference data were collected from multiple sources. A total of 321 points were collected from the field using cellphone-based applications (Figure 7) which allowed for the collection of geotagged photos in offline mode as well. The collected validation points and photos were uploaded to the server directly, i.e., without manual intervention. Moreover, 1700 permanent sample plots from FRTC's Forest Resource Assessment were also used. An additional 2000 points were collected using the latest version of CEO. The spatial distribution of points across the country used for accuracy assessment is provided in Figure 8.

Figure 6: **Necessary steps used for land cover mapping for Nepal**

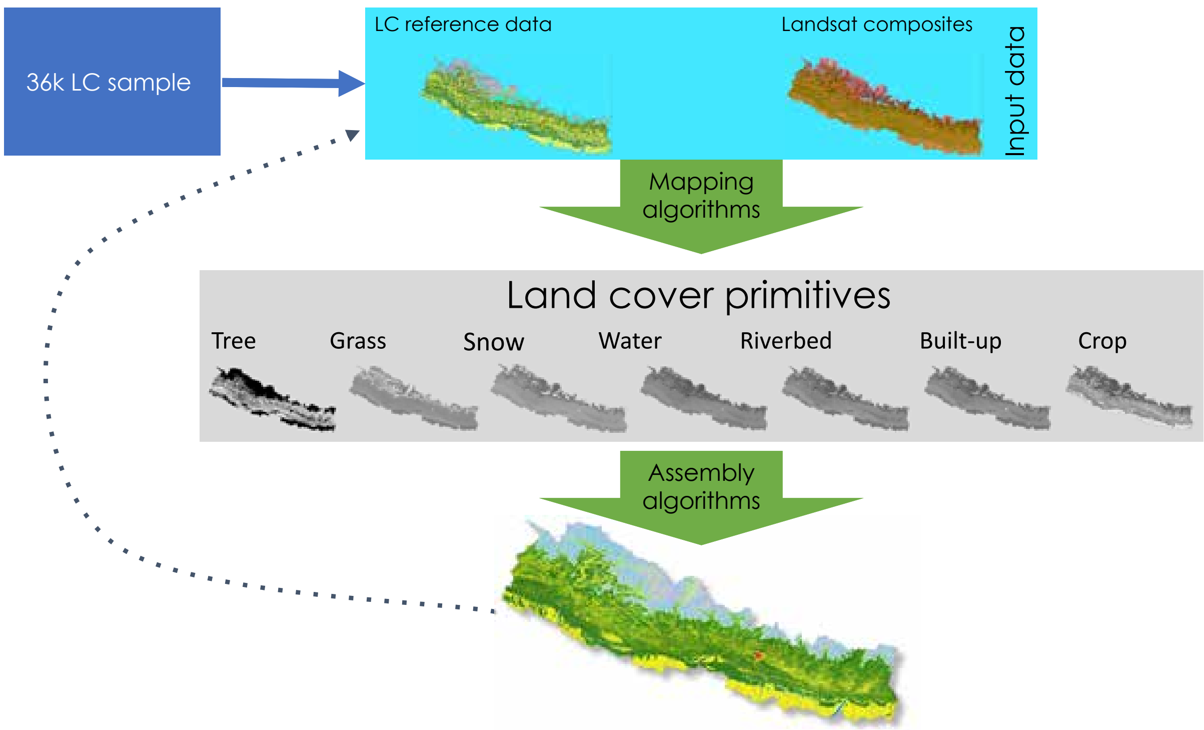


Figure 7: **Screenshot of the mobile application used for field-based validation of land cover**

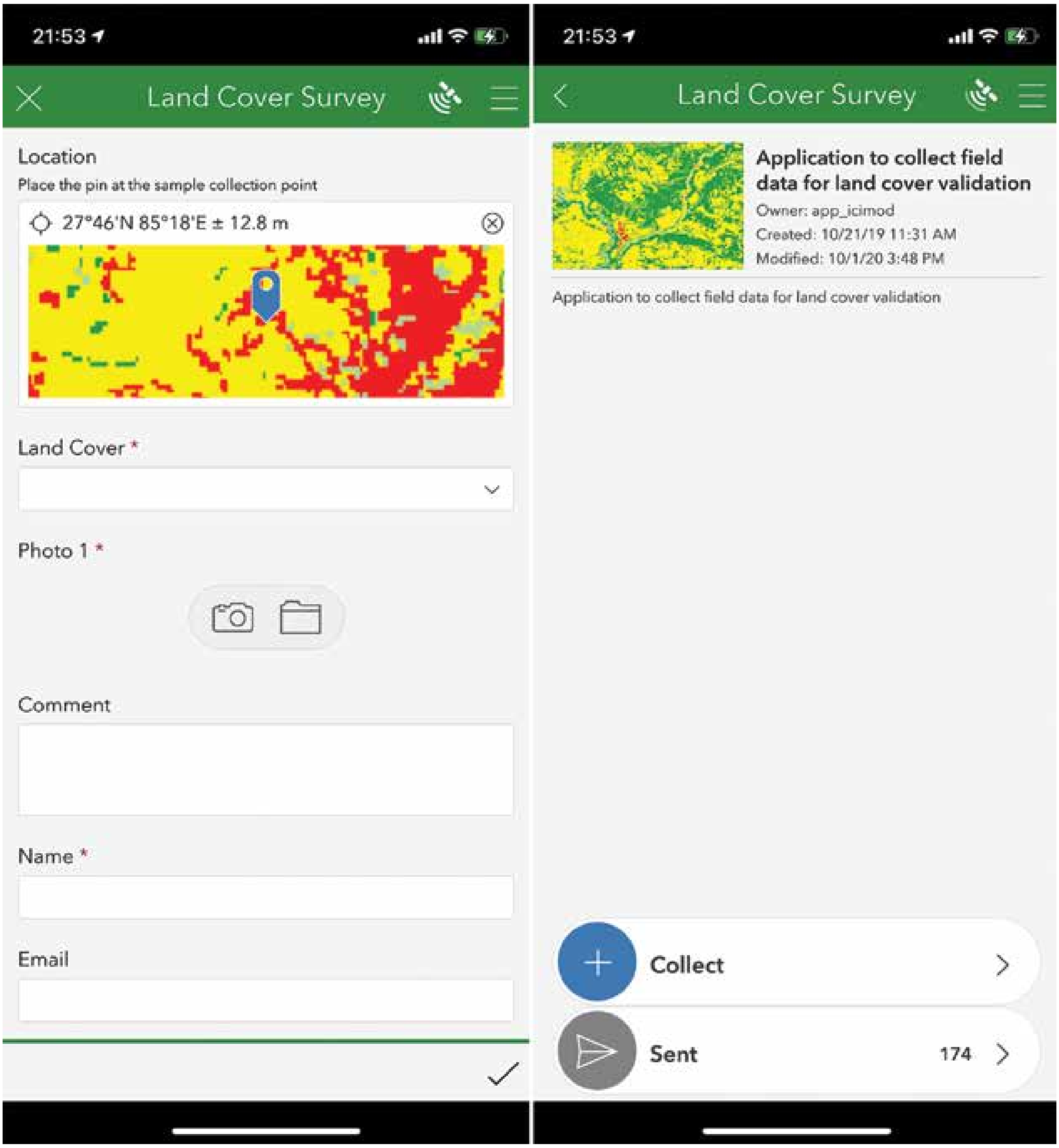
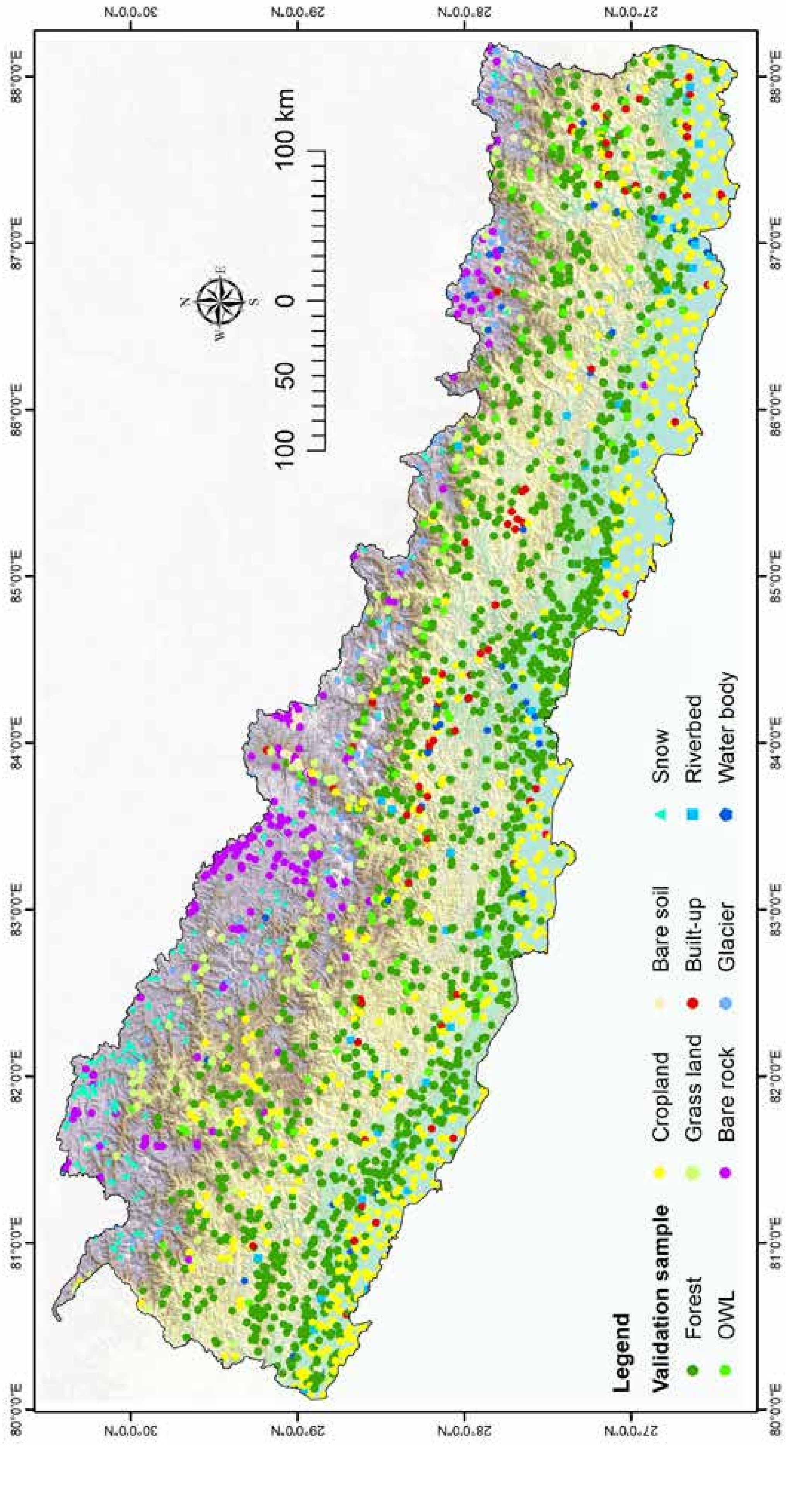


Figure 8: Spatial distribution of validation points used for Nepal land cover



4. Results and discussion

4.1 National land cover statistics

Land cover area statistics from the land cover map of 2000 and 2019 are presented in Table 3. The land cover maps for 2000 and 2019 are shown in Figures 9 and 10. The result showed that the primary land cover in the country is forest, followed by cropland and grassland. In 2019, forest cover is the dominant land cover with 41.69%, followed by 24.21% cropland and 13.27% grassland. Around 20% land cover is occupied by snow, bare rock, OWL, glacier, riverbed, built-up, water body and bare soil in descending order. In the year 2000, forest cover is the dominant land cover with 39.99%, followed by 26.31% cropland and 13.95% grassland. Around 20% of the land cover is occupied by bare rock, snow, OWL, glacier, riverbed, water body, built-up and bare soil in descending order. Overall, forest cover is increased by 1.7% between 2000 and 2019. Similarly, OWL is increased from 3.57 % in 2000 to 3.62% in 2019.

Table 3: **Nepal land cover statistics between 2000 and 2019**

	Area (2000)		Area (2019)	
Land cover	**Hectare**	**%**	**Hectare**	**%**
Water body	65824	0.44	71587	0.48
Glacier	464468	3.14	463872	3.14
Snow	576278	3.90	930199	6.29
Forest	5915518	39.99	6166766	41.69
Riverbed	170699	1.15	163721	1.11
Built-up	25487	0.17	78296	0.53
Cropland	3891500	26.31	3581047	24.21
Bare soil	156	0.00	4033	0.03
Bare rock	1091125	7.38	835030	5.64
Grassland	2064046	13.95	1963286	13.27
OWL	527915	3.57	535179	3.62
Total	**14793015**	**100**	**14793015**	**100**

Note: The total area of the country used by LRMP, NFI 1994 and FRA 2015 was 147,184 km^2, 147,181 km^2, and 147,734 km^2 respectively while NLCMS used the mapped area of **147,930.15 km^2** applying the Lambert Conformal Conic (LCC) map projection.

Figure 9: **Land cover map of Nepal, 2000**

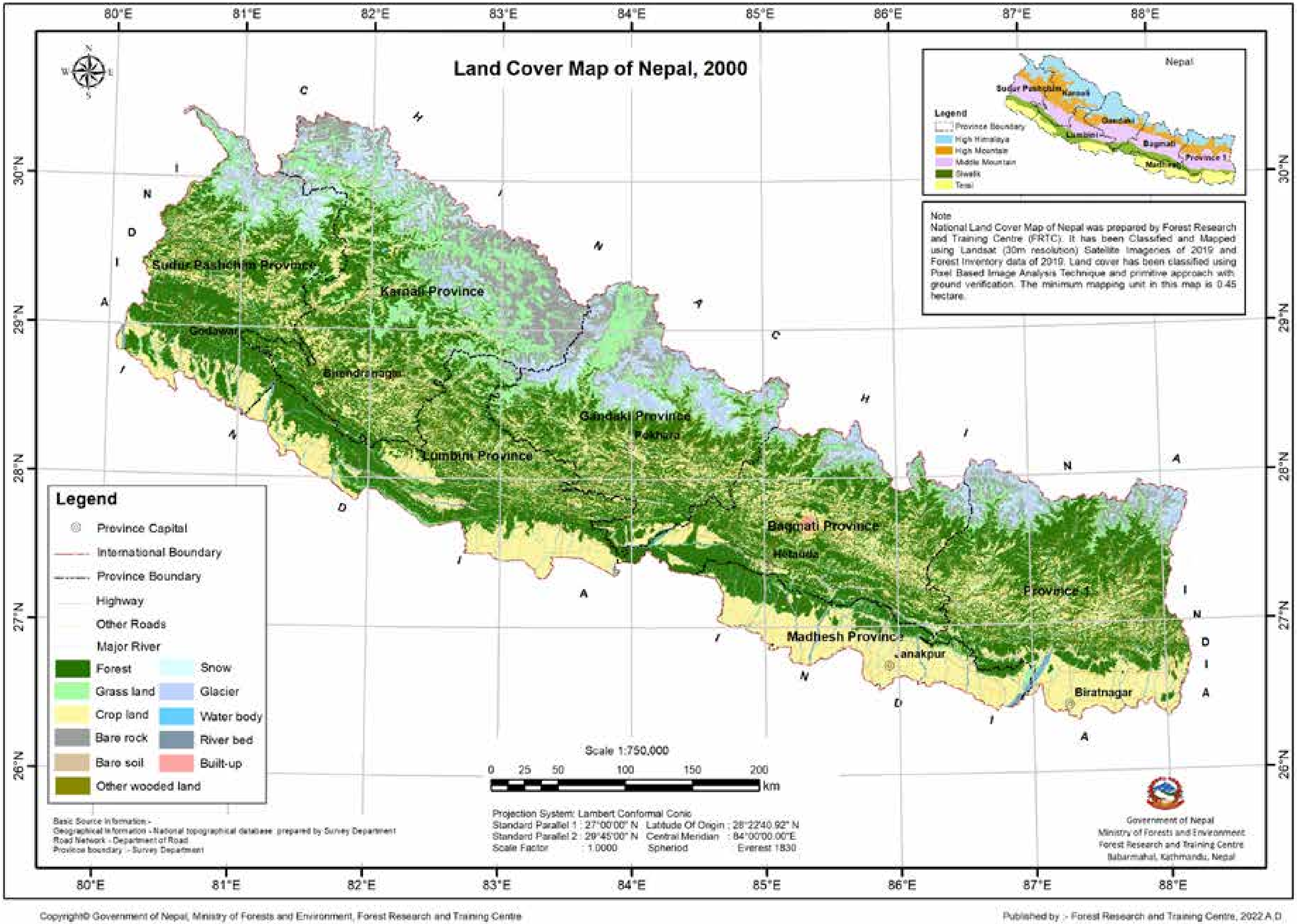


Figure 10: **Land cover map of Nepal, 2019**

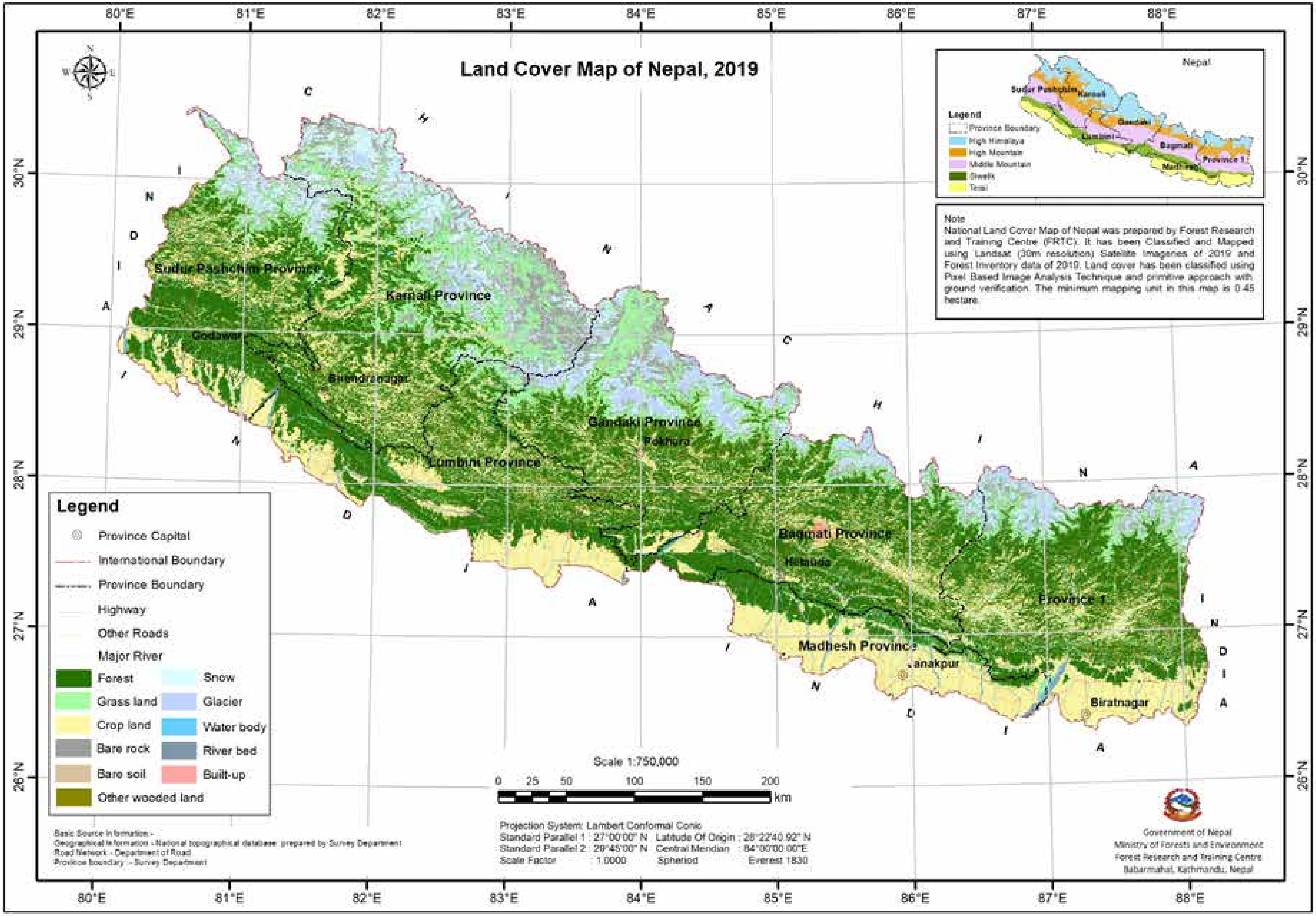


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Table 4: **Province-wise land cover area between 2000 and 2019**

	Province 1		Madhesh		Bagmati		Gandaki		Lumbini		Karnali		Sudur Paschim	
Land cover (ha)	2000	2019	2000	2019	2000	2019	2000	2019	2000	2019	2000	2019	2000	2019
Water body	15673	14581	6057	7628	8054	8064	8279	9292	9682	10854	11758	10944	6321	8912
Glacier	108988	108854	0	0	45886	45829	172126	171999	1516	1513	97084	96912	38868	38790
Snow	55406	105074	0	0	34633	32702	175172	174961	1986	6988	199078	460250	110003	132151
Forest	1119675	1157905	249520	237636	1051780	1154685	716940	787865	944086	996941	858890	837016	974629	989268
Riverbed	30656	30646	48326	46884	27768	24462	9216	8348	30142	29629	4307	4110	20284	18945
Built-up	2133	10640	2904	7581	9791	25003	4157	7984	1739	12383	4145	10191	617	3879
Cropland	797953	740067	599742	592648	556476	459982	339430	270974	731286	678730	390291	385884	476322	463388
Bare soil	8	35	0	97	0	9	5	3248	0	11	10	369	131	235
Bare rock	127273	77224	0	0	62665	53258	226595	195827	11204	12108	592157	440881	71231	64419
Grassland	227516	242561	49767	54831	168392	165963	423625	446917	142609	111356	798518	718244	253620	231768
OWL	119979	117673	2614	11624	62983	58473	120516	118648	56195	69932	108584	100020	57044	57314
Total	2605260	2605260	958930	958930	2028428	2028428	2196062	2196062	1930445	1930445	3064821	3064821	2009069	2009069

Table 5: **Land cover in different physiographic regions between 2000 and 2019**

	Terai		Siwalik		Middle Mountain		High Mountain		High Himal	
Land cover (ha)	2000	2019	2000	2019	2000	2019	2000	2019	2000	2019
Water body	20195	23178	12358	14069	14897	17538	5005	4890	13370	11912
Glacier	0	0	0	0	0	0	57	57	464411	463815
Snow	0	0	0	0	0	2	7539	12152	568739	918046
Forest	373238	392240	1322210	1345929	2361959	2611307	1727499	1701021	130611	116269
Riverbed	87574	86691	61906	58383	17672	14928	949	796	2598	2922
Built-up	5561	24562	1794	9520	10323	28320	1648	6091	6160	9804
Cropland	1461951	1428152	377880	344532	1591882	1358332	456703	447024	3085	3007
Bare soil	0	108	0	28	0	9	0	24	156	3864
Bare rock	0	0	0	1	0	44	13958	12725	1077167	822259
Grassland	60406	46681	104579	85894	139343	114379	522467	555641	1237251	1160690
OWL	10026	17338	14880	37251	166191	157408	270888	266293	65930	56889
	2020951	2020970	1897607	1897626	4304266	4304285	3008714	3008733	3571477	3571496

4.1.1 Land cover at the province level

Land cover statistics at the province level from 2000 and 2019 showed that land cover scenarios varied across provinces. Table 4 shows the land cover distribution in provinces for 2000 and 2019.

Forest cover is predominant in all the provinces except in Madhesh province. Apart from Madhesh province and Karnali Province, forest cover is increasing from 2000 to 2019. The area covered by OWL is increased tremendously in Madhesh province and slightly in Lumbini and Sudurpaschim province. However, OWL is decreased in Province 1, Bagmati Province, Gandaki Province and Karnali Province. Builtup area is increased in all province throughout the study period. In contrast, cropland is decreased in all provinces.

4.1.2 Land cover in different physiographic regions

Land cover statistics for different physiographic regions are shown in Table 5. Cropland is a dominant land cover in the Terai; forest is dominant in the Siwalik, Middle Mountain and High Mountain physiographic regions. In contrast, grassland is dominating in the High Himal. This trend remained the same in 2000 and 2019 for all physiographic regions.

Forest cover is increased in the Terai, Siwalik and Middle Mountain regions whereas it decreased in High Mountain and High Himal from 2000 to 2019. Moreover, OWL is increased in Terai and Siwalik region whereas it decreased in the middle Mountain, High Mountain and High Himal regions from 2000 to 2019. Cropland is in decreasing order in all the physiographic regions. In contrast, built-up area increased gradually in all regions. Grassland is decreased in all physiographic regions except in the High Mountain region.

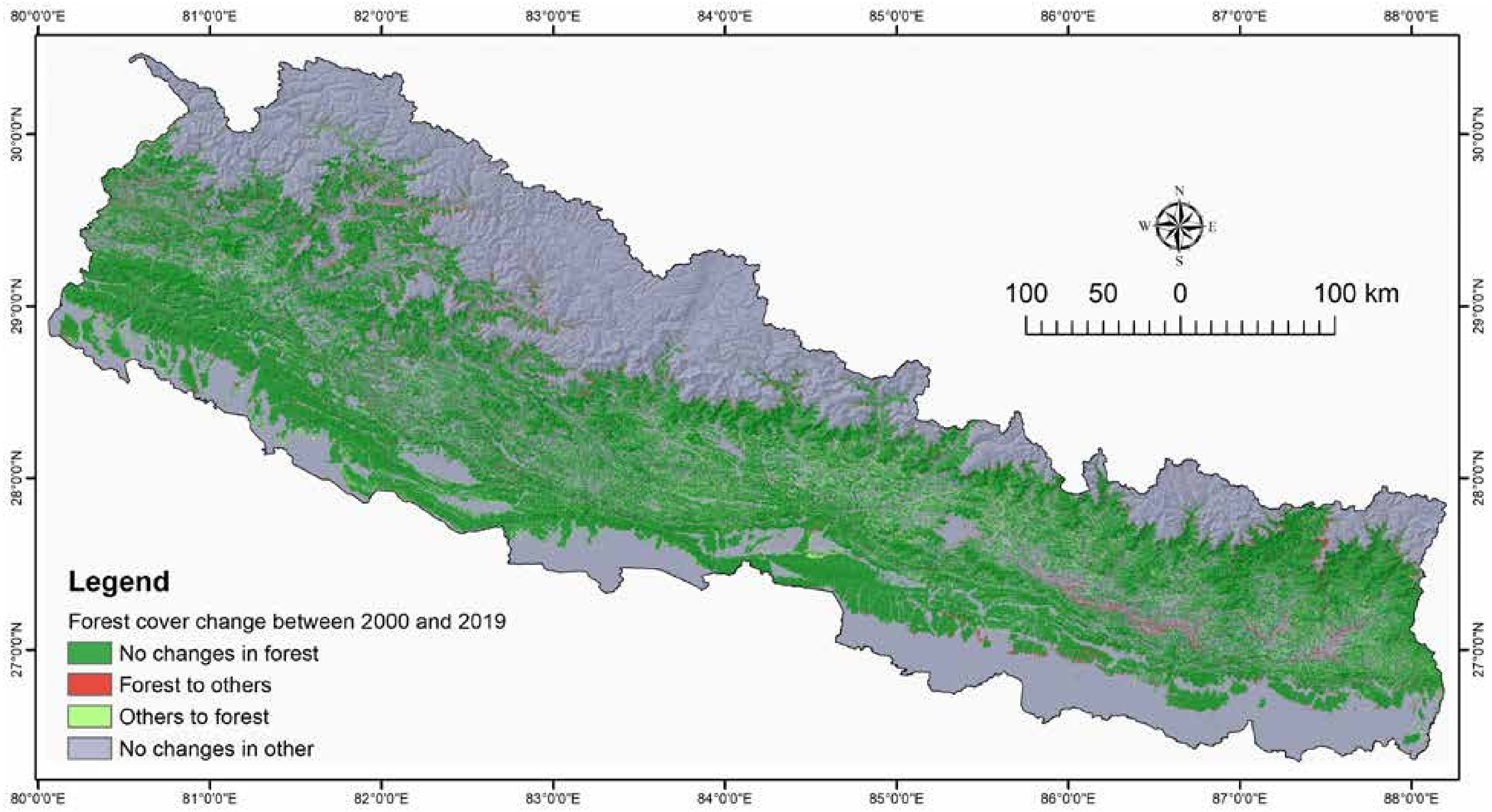
4.2 Land cover change analysis

The change matrix was produced (Table 6) using 2000 and 2019 land cover data. Overall, forest area has been increasing from 2000 to 2019, whereas cropland and grassland have been decreasing. Built-up and bare soil areas are also increasing at higher rates.

Table 6: **Land cover changes between 2000 and 2019**

2000 (ha)	2019 (ha)											
Land cover	**Water body**	**Glacier**	**Snow**	**Forest**	**Riverbed**	**Built-up**	**Cropland**	**Bare soil**	**Bare rock**	**Grassland**	**OWL**	**Total**
Water body	42232	3	964	613	15702	215	1991	111	561	3248	185	65824
Glacier	1	463550	701	0	0	0	0	0	62	153	0	464468
Snow	79	132	458738	67	5	154	0	50	72608	44150	293	576278
Forest	1250	0	553	5589552	191	1081	118385	26	422	95268	108790	5915518
Riverbed	16827	0	5	290	144696	2631	4911	1	39	1237	61	170699
Built-up	45	0	121	3	14	25156	31	1	50	65	0	25487
Cropland	6618	0	3	370805	1969	43598	3420253	4	136	9531	38582	3891500
Bare soil	4	0	25	0	0	0	0	37	62	28	0	156
Bare rock	273	104	347071	67	65	804	2	975	605454	135808	502	1091125
Grassland	4081	81	120314	109282	1068	4569	15341	2824	154405	1601339	50742	2064046
OWL	176	1	1702	96087	11	88	20132	5	1231	72458	336023	527915
Total	**71587**	**463872**	**930199**	**6166766**	**163721**	**78296**	**3581047**	**4033**	**835030**	**1963286**	**535179**	**14793015**

Figure 11: **Spatial distribution of changes in forest area between 2000 and 2019**



Forest cover has increased by 1.70%. The major land cover conversion to the forest conversion is from cropland and OWL. On the other hand, cropland has decreased by 2.10%. A major part of the cropland was converted to forest, grassland and built-up area. Similarly, grassland decreased by 0.684% and built-up area increased by 0.36%. However, built-up areas cover a very small portion, i.e., less than a percent of the country. Areas classified as glacier and water body remained constant over the 20 years. Area classified as snow has been fluctuating, possibly due to change in annual precipitation patterns across the country.

Due to variations in areas classified as snow, there are variations in bare rock and grassland area because snow normally covers these types of land; in the absence of snow cover, such areas are exposed. Overall, Nepal's land cover is experiencing a minimal level of conversion within the 11 classes.

Forest has mainly been converted from OWL, cropland, and grassland from 2000 to 2019. OWL mainly changed to forest, whereas a large portion of cropland has turned to forest, OWL, built-up and grassland from 2000 to 2019. Figure 11 shows the spatial distribution of forest cover change to other categories and vice versa. From these maps, it is apparent that in the eastern Terai, forest area has been converted to other land cover types, whereas in the Middle Mountain region, other land cover types have been converted to forest area (Figure 12).

4.3 Accuracy assessment

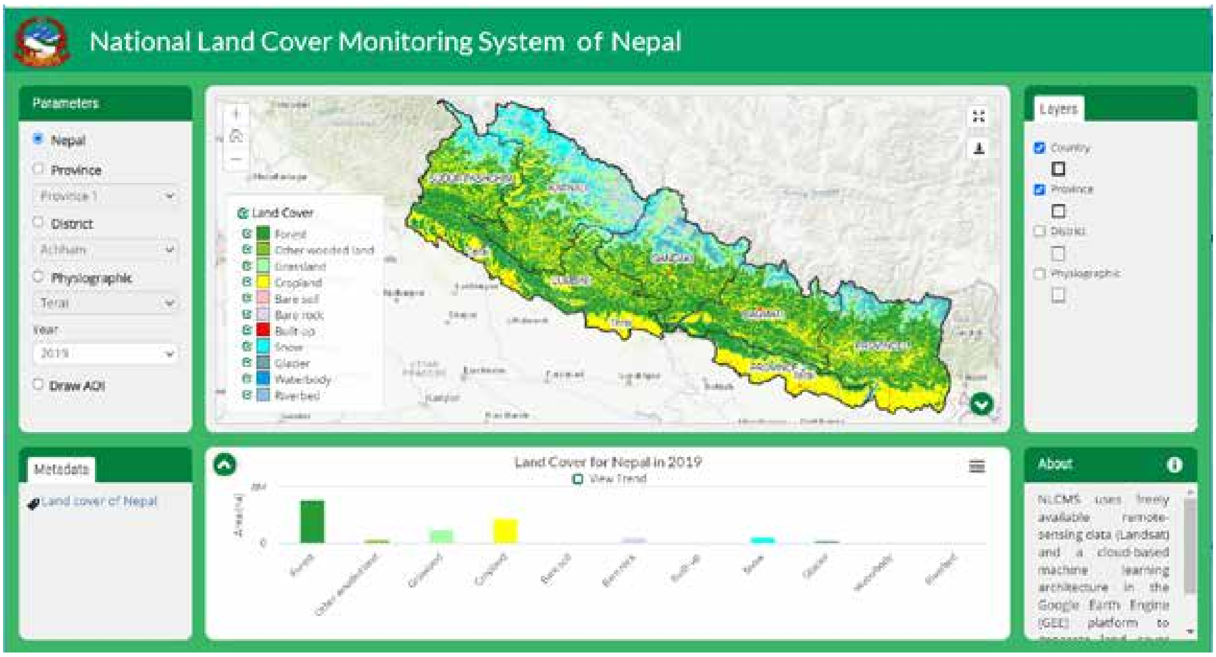
The error matrix generated from the accuracy assessment of the 2019 land cover is shown in Tables 7 and 8. The overall accuracy of the classification for 2019 is 84.80 %, and the overall kappa statistic is 0.73. The highest accuracy obtained was for the glacier class. This data was used from ICIMOD's glacier

Table 7: **Accuracy assessment of land cover 2019**

Land cover	**Water body**	**Glacier**	**Snow**	**Forest**	**Riverbed**	**Built-up**	**Cropland**	**Bare soil**	**Bare rock**	**Grassland**	**OWL**	**Total**	**User's accuracy (%)**
Water body	47	0	0	1	4	1	0	0	0	0	0	53	82.46
Glacier	0	61	0	0	0	0	0	0	0	0	0	61	100.00%
Snow	0	0	132	0	0	0	0	0	4	1	0	137	90.41
Forest	0	0	0	2360	0	0	8	0	0	1	17	2386	98.66
Riverbed	1	0	0	0	32	0	0	0	0	2	1	36	88.89
Built-up	0	0	0	4	0	74	3	0	4	5	2	92	77.89
Cropland	2	0	0	317	5	11	555	0	0	52	9	951	57.69
Bare soil	0	0	0	0	0	0	0	11	4	0	0	15	73.33
Bare rock	0	0	3	0	1	0	0	2	122	0	0	128	93.13
Grassland	1	0	1	45	2	1	17	5	10	162	10	254	58.27
OWL	0	0	0	122	0	0	1	0	0	2	84	209	40.19
Total	**51**	**61**	**136**	**2849**	**44**	**87**	**585**	**18**	**144**	**225**	**123**	**4323**	
Producer's accuracy (%)	**85.45**	**100.00**	**93.62**	**82.84**	**62.75**	**79.57**	**94.87**	**61.11**	**73.05**	**72.00**	**60.87**		

Table 8: **Accuracy assessment of land cover (IPCC class) 2019**								
Land cover	**Forest**	**Cropland**	**Grassland**	**Wetland**	**Built-up**	**Others**	**Total**	**User's (%)**
Forest	2533	2	0	0	0	0	2536	99.88
Cropland	274	488	39	1	2	0	804	60.70
Grassland	48	18	110	1	1	42	220	50.00
Wetland	1	0	3	74	0	0	78	94.87
Built-up	1	0	0	0	30	0	31	96.77
Others	0	0	0	0	0	352	352	100.00
Total	2857	508	153	76	33	394	4021	
Producer's accuracy (%)	88.66	96.06	71.90	97.37	90.91	89.34		

database produced by object-based image classification and visual interpretation (Bajracharya and Shrestha, 2011). User's accuracy for the forest was very high (98.66%) compared to the producer's accuracy (82.84%). This means all the classified forest maps matched with reference samples. Some of the reference samples were classified as other land cover classes. This is because some of the validation samples were collected from areas located at the edge of forested areas where pixels were mixed with cropland, OWL or grasslands with sparse trees. Accuracy for OWL was low because mapping this class using Landsat 30-meter satellite images was challenging. The OWL class is similar to a sparse forest and only differs in percent of tree cover. Similarly, the overall accuracy of the land cover (IPCC classes) 2019 is 89.21%, and the overall kappa statistic is 0.79.



The National Land Cover Monitoring System of Nepal – a web-based application provides land cover information at the national and provincial levels for 2000-2019. Users can also for access land cover statistics for different physiographic regions in Nepal or specify a defined area of interest.

5. Conclusion

Overall, the land cover development process is based on the already established robust method developed through international co-operation among SERVIR hubs, NASA, SilvaCarbon, UMD and USFS. The National Land Cover Monitoring System successfully developed annual land cover maps for Nepal from 2000 to 2019 using consistent satellite data and robust machine learning methods in the GEE cloud-based platform. The use of GEE helped us to analyse a large number of Landsat satellite images without the need to download them and at no cost. Furthermore, image pre-processing (atmospheric and topographic correction), covariate generation and final image classification were easily carried out for Landsat images within a short period. By using the NLCMS, we can generate land cover for the upcoming year after one or two months of ending the previous year. This system also eliminates the problem of seasonal effects on satellite imageries after making an annual composite.

The technical specification for the development of the NLCMS was approved by the Mapping Committee, Technical Sub-committee of the Survey Department. This system was established by conducting several meetings and getting consensus from national stakeholders related to land cover from the very onset.

5.1 Implications of NLCMS

This dataset will be highly useful for national and international reporting. Even though the data and methodology used for the NLCMS is different from the Forest Resource Assessment project, the total forest and OWL land cover differ only by 0.25%. So, this data will be used for the REDD MRV process. This land cover data will be helpful in preparing a Long-Term Strategy (LTS) and Nepal's Nationally Determined Contribution (NDC). Similarly, it will be used for preparing a land account system during the System of Environmental Economic Accounting (SEEA) development process. The primary use of this land cover change information will be in the formulation of policies and strategies for conservation and sustainable ecosystems management. These maps will be further useful in mapping ecosystems and forest types in Nepal. The land cover can be easily customized into six land cover classes for IPCC reporting, and three land cover classes for GFRA reporting, and for any other international reporting mechanisms accordingly.

5.2 Limitations

A large number of spatially distributed training samples helps to generate land cover maps accurately. However, during reference data collection, only satellite images from recent years were available in CEO desktop. The availability of more images from the previous years would have improved efficiency and increased the ability to generate reference data for training and evaluation of image classification. Leveraging mobile apps for land cover validation was convenient. However, field-based methods do not allow us to collect historical data for a particular land cover. Also, inaccessibility and rough topography and the COVID-19 pandemic limited collection of validation points across Nepal. The land cover is based on a Landsat 30 m resolution with each image pixel measuring 0.09 ha. Only a single land cover type is mapped based on a majority land cover representation when more than one land cover type exists within the pixel.

Errors from such a type of mixed pixel effect is almost impossible to overcome. The minimum mapping unit of this land cover is 0.5 ha, so it is not comparable with the the land cover data with higher spatial resolutions. There are technical challenges in mapping the OWL class due to spectral similarity and unavailability of information on tree height or species information.

5.3 Way forward

Land cover mapping methodologies are always changing and improving. The NLCMS system was designed to leverage open platform architecture allowing flexibility to adopt emerging technologies for sustained implementation by end-users. The current land cover data was produced for 11 classes; however, further classification of forests based on species distribution is also necessary for conservation and ecosystem management. Forest structure, degradation, and biomass estimation are equally important. Sample-based area estimation (for estimating land cover and land cover change statistics) will be used in further works to gauge the level of uncertainty of the map area.

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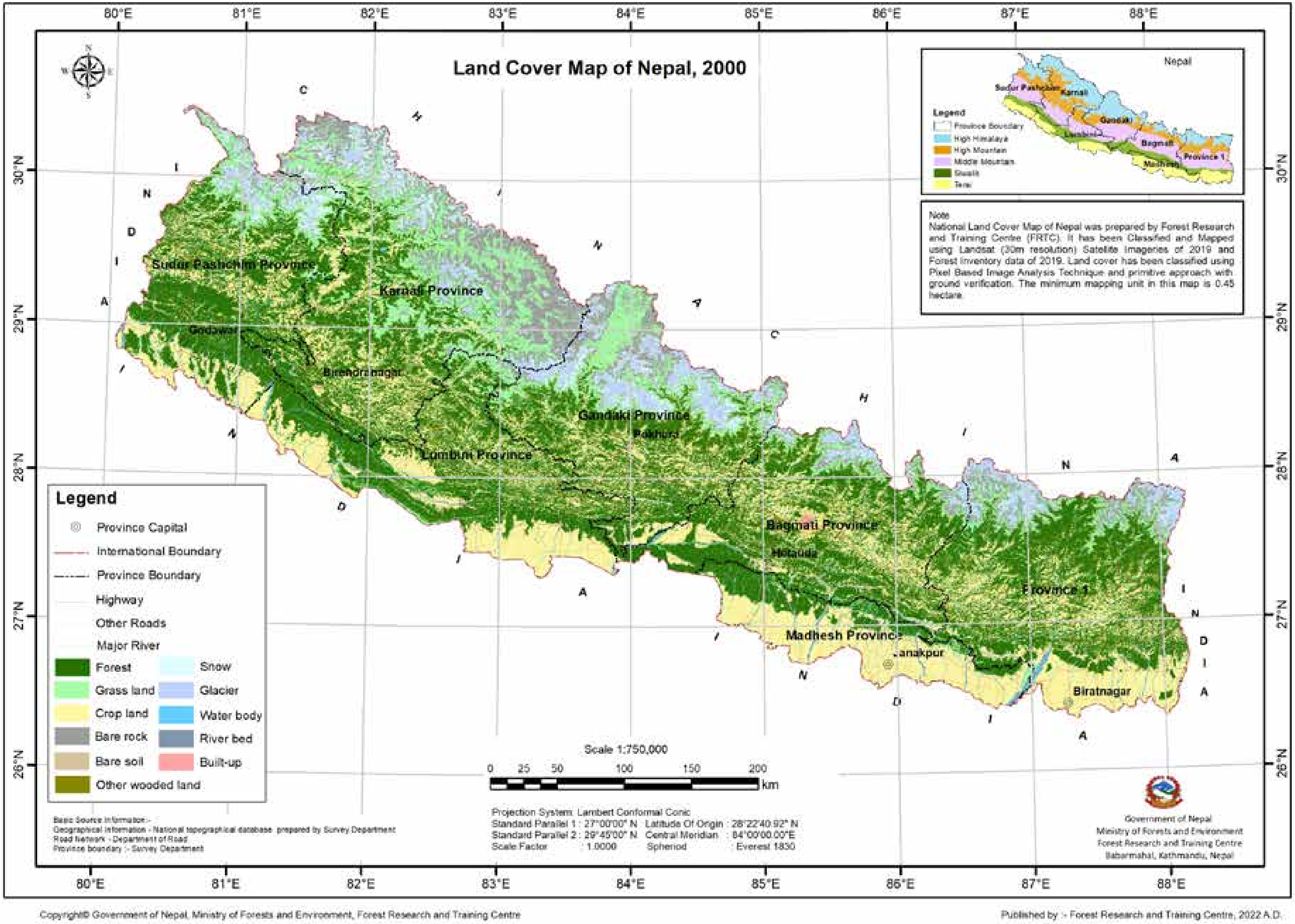
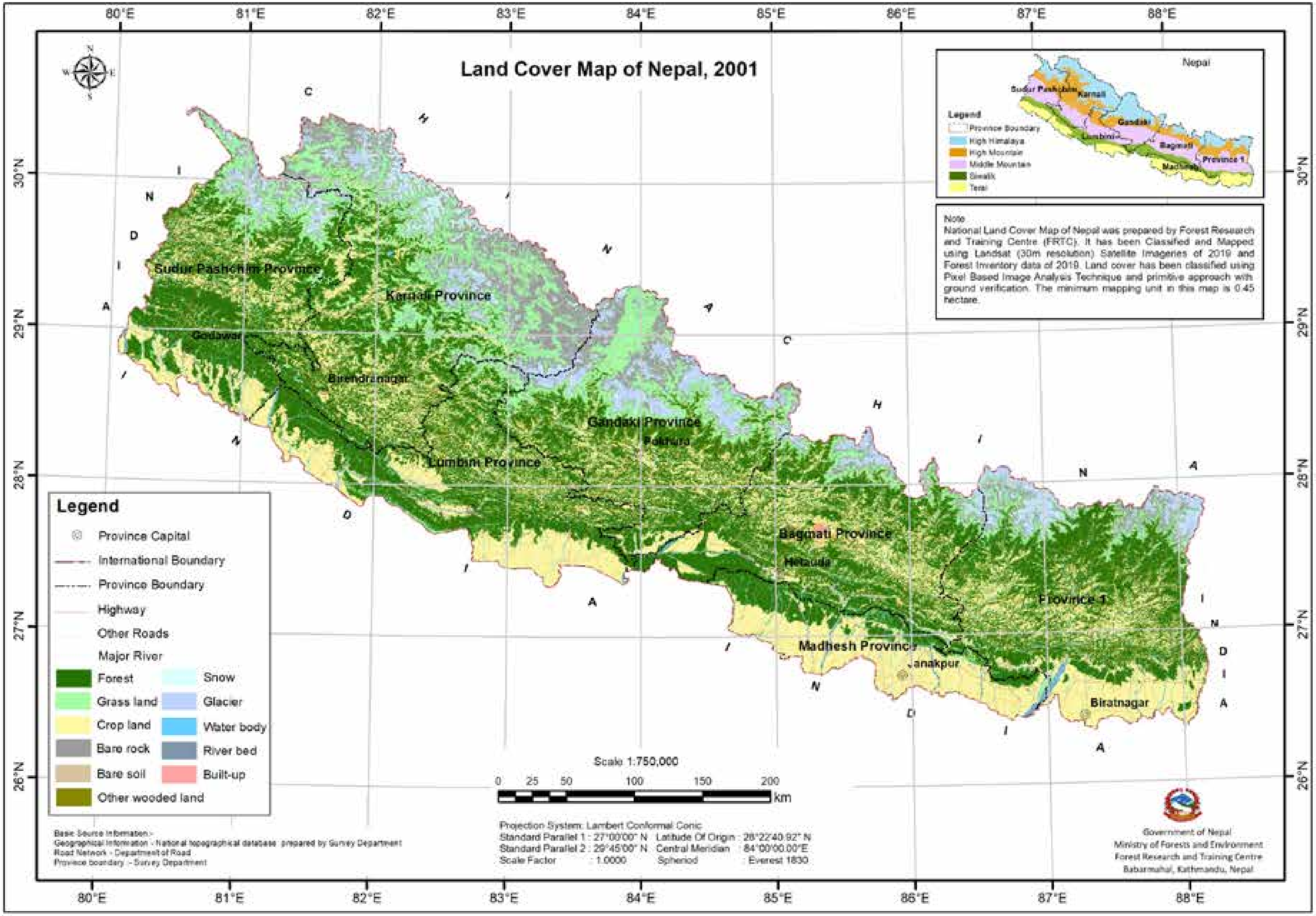
Annex: National land cover map for 2000-2019





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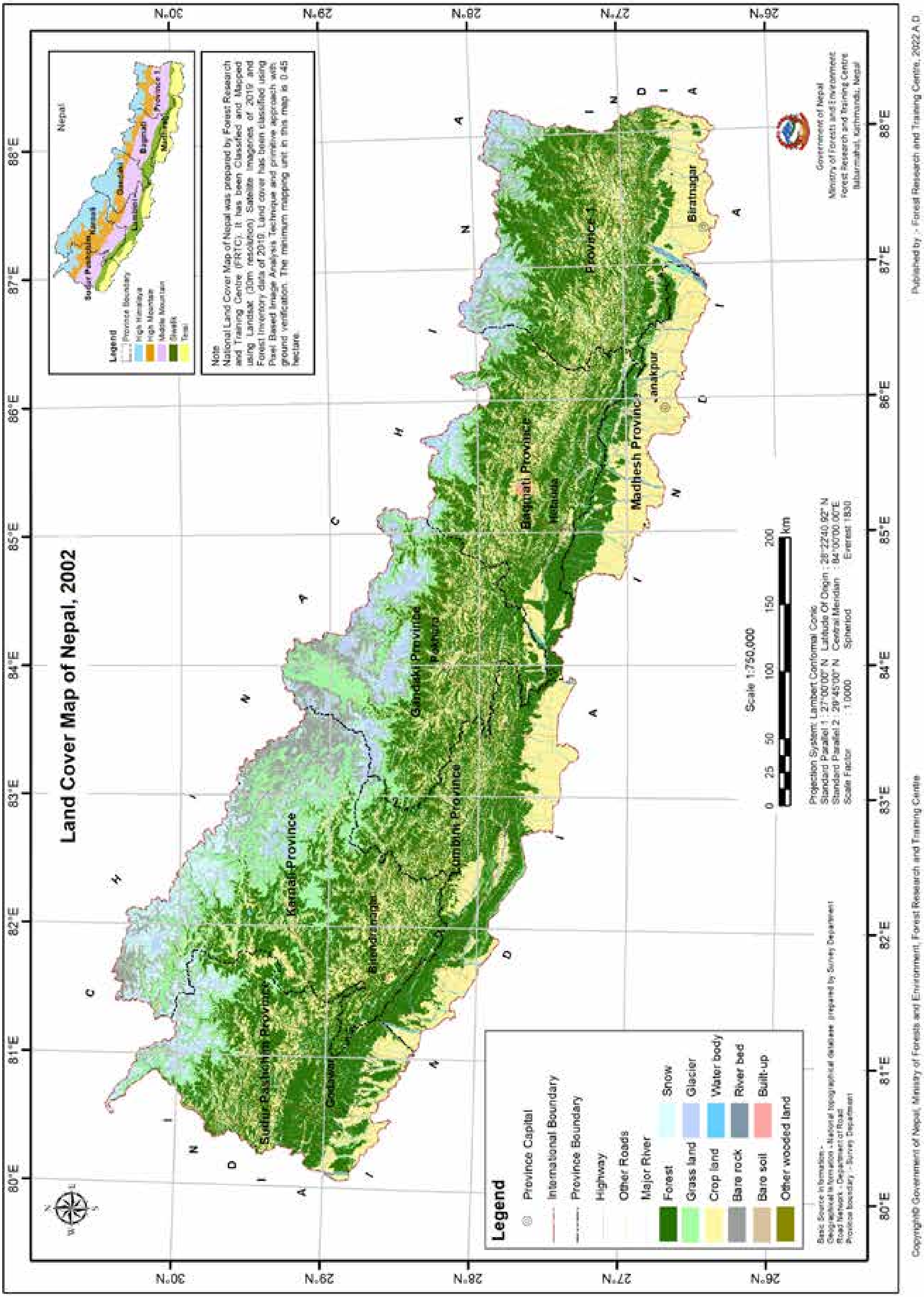
Land Cover Map of Nepal, 2002
Legend
Province Capital
International Boundary
Province Boundary
Highway
Other Roads
Major River
Forest
Grass land
Crop land
Bare rock
Bare soil
Other wooded land
Snow
Glacier
Water body
River bed
Built-up
Sudur Pashchim Province
Karnali Province
Lumbini Province
Gandaki Province
Bagmati Province
Madhesh Province
Province 1
Biratnagar
Janakpur
Hetauda
Pokhara
Birendranagar
Godawari
Scale 1:750,000
Projection System: Lambert Conformal Conic
Nepal
Legend
Province Boundary
High Himalaya
High Mountain
Middle Mountain
Siwalik
Terai
Government of Nepal
Ministry of Forests and Environment
Forest Research and Training Centre
Babarmahal, Kathmandu, Nepal
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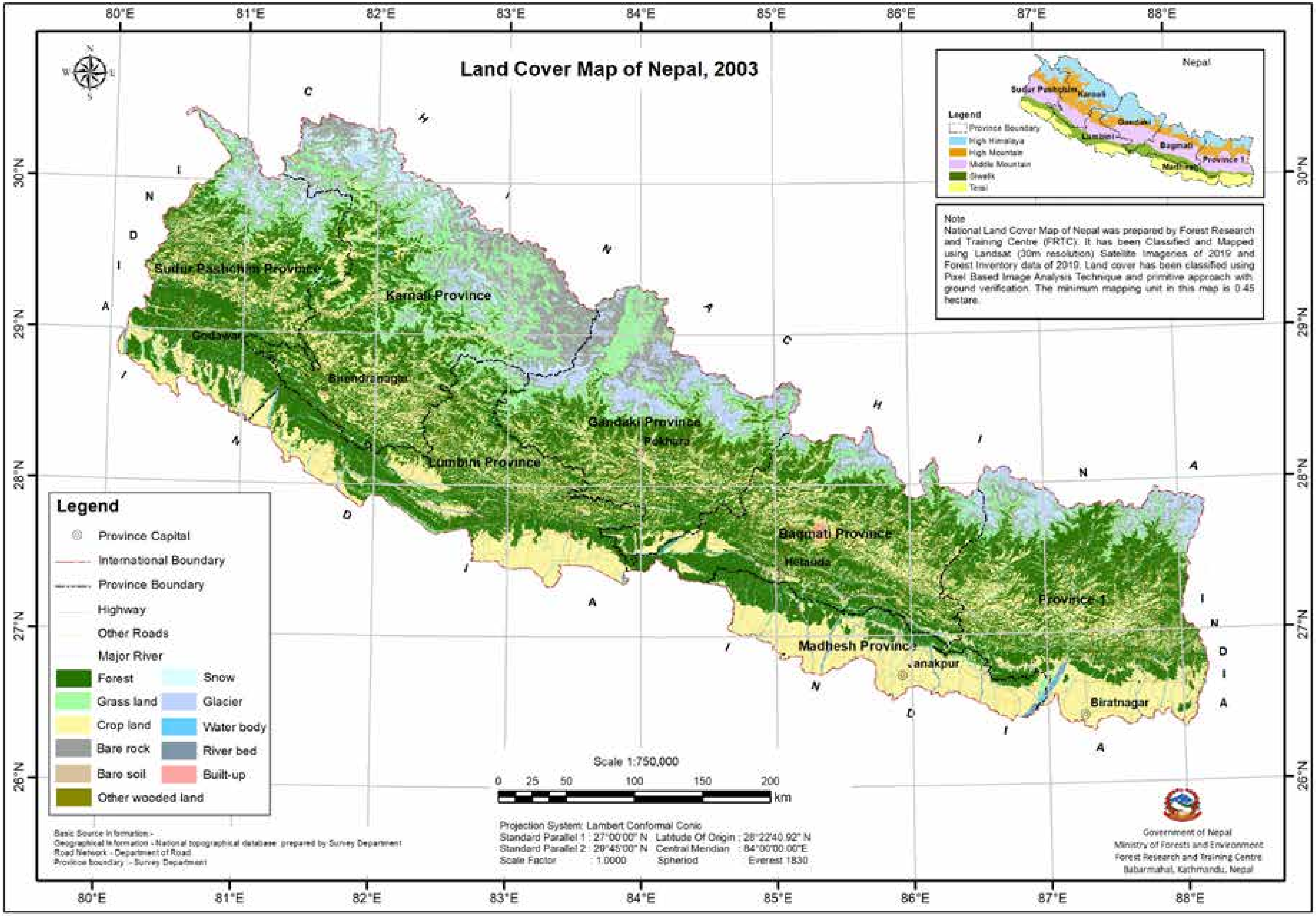
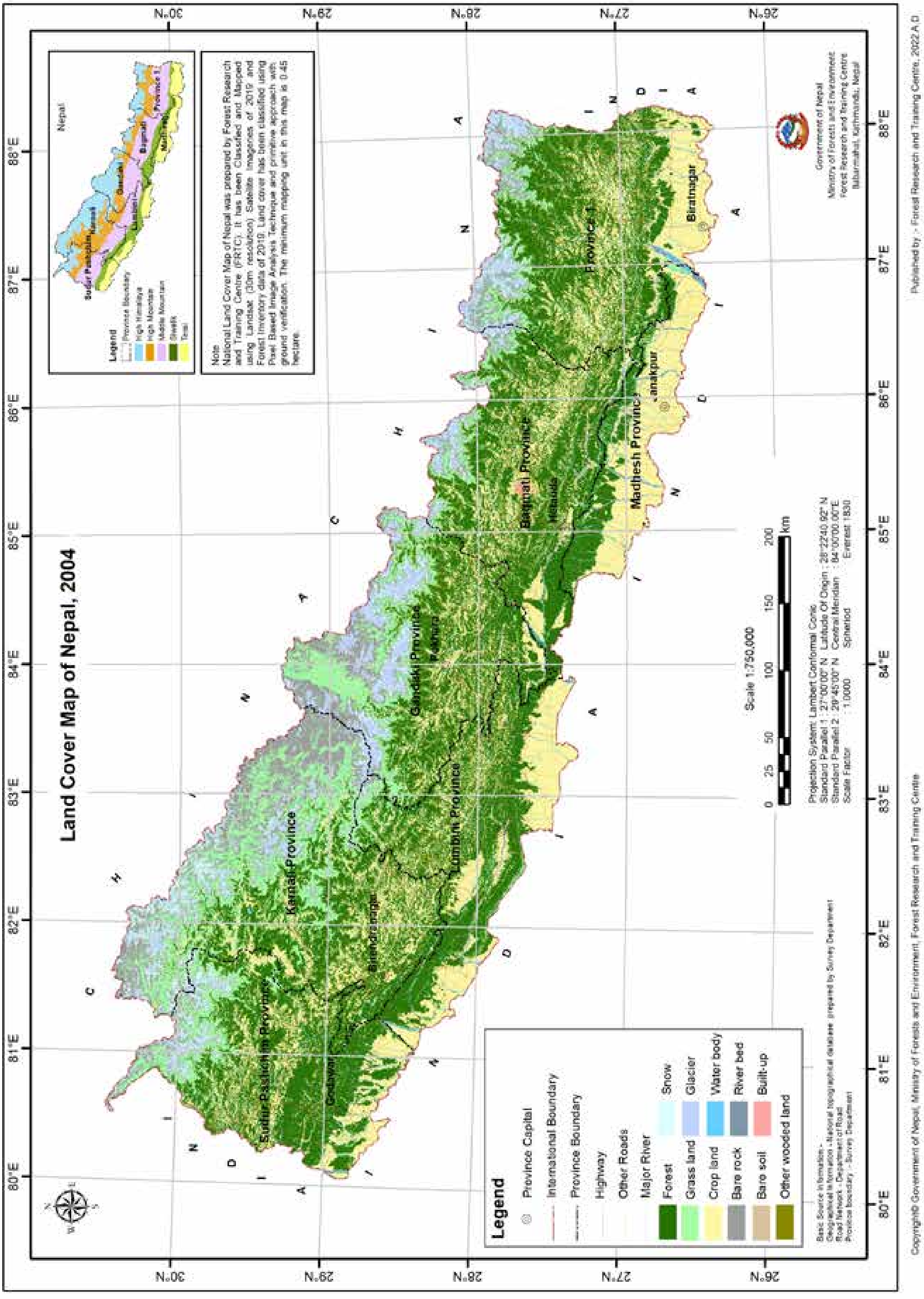


Published by :- Forest Research and Training Centre, 2022 A.D


Land Cover Map of Nepal, 2004
Legend
Province Capital
International Boundary
Province Boundary
Highway
Other Roads
Major River
Forest
Grass land
Crop land
Bare rock
Bare soil
Other wooded land
Snow
Glacier
Water body
River bed
Built-up
Note
National Land Cover Map of Nepal was prepared by Forest Research and Training Centre (FRTC). It has been Classified and Mapped using Landsat (30m resolution) Satellite Imageries of 2019 and Forest Inventory data of 2010. Land cover has been classified using Pixel Based Image Analysis Technique and primitive approach with ground verification. The minimum mapping unit in this map is 0.45 hectare.
Nepal
Sudur Pashchim Province
Karnali Province
Lumbini Province
Gandaki Province
Bagmati Province
Madhesh Province
Province 1
Pokhara
Hetauda
Janakpur
Biratnagar
Scale 1:750,000
0 25 50 100 150 200 km
Projection System: Lambert Conformal Conic
Government of Nepal
Ministry of Forests and Environment
Forest Research and Training Centre
Babarmahal, Kathmandu, Nepal
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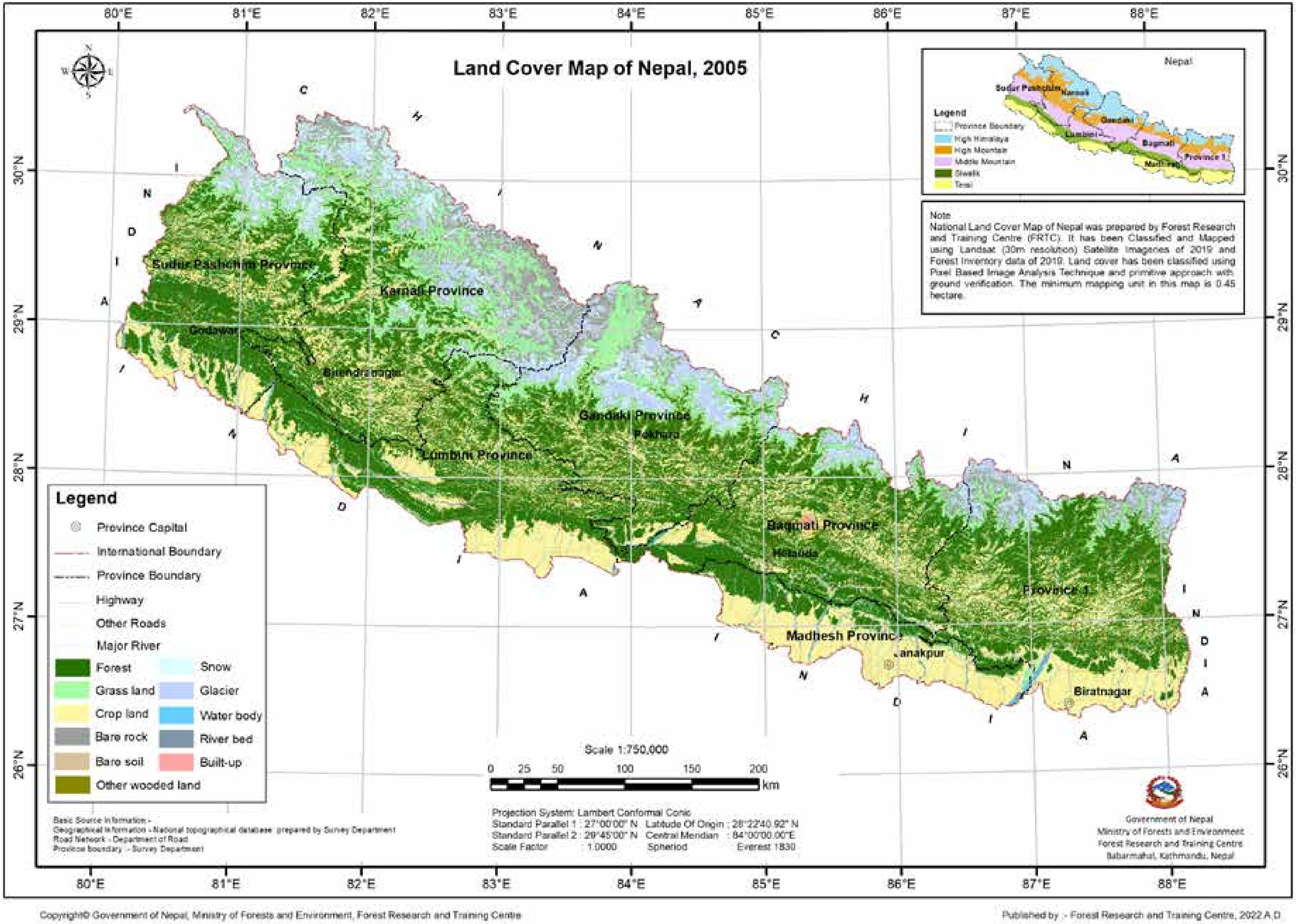

Land Cover Map of Nepal, 2005
Nepal
Legend
Province Boundary
High Himalaya
High Mountain
Middle Mountain
Siwalik
Terai
Sudur Pashchim
Karnali
Gandaki
Lumbini
Bagmati
Province 1
Madhesh
Note
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Sudur Pashchim Province
Karnali Province
Godawari
Birendranagar
Gandaki Province
Pokhara
Lumbini Province
Bagmati Province
Hetauda
Province 1
Madhesh Province
Janakpur
Biratnagar
C H I N A
I N D I A
Legend
Province Capital
International Boundary
Province Boundary
Highway
Other Roads
Major River
Forest
Grass land
Crop land
Bare rock
Bare soil
Other wooded land
Snow
Glacier
Water body
River bed
Built-up
Scale 1:750,000
0 25 50 100 150 200 km
Basic Source Information -
Geographical Information - National topographical database prepared by Survey Department
Road Network - Department of Road
Province boundary :- Survey Department
Projection System: Lambert Conformal Conic
Standard Parallel 1 : 27°00'00" N Latitude Of Origin : 28°22'40.92" N
Standard Parallel 2 : 29°45'00" N Central Meridian : 84°00'00.00"E
Scale Factor : 1.0000 Spheriod Everest 1830
Government of Nepal
Ministry of Forests and Environment
Forest Research and Training Centre
Babarmahal, Kathmandu, Nepal
80°E 81°E 82°E 83°E 84°E 85°E 86°E 87°E 88°E
26°N 27°N 28°N 29°N 30°N
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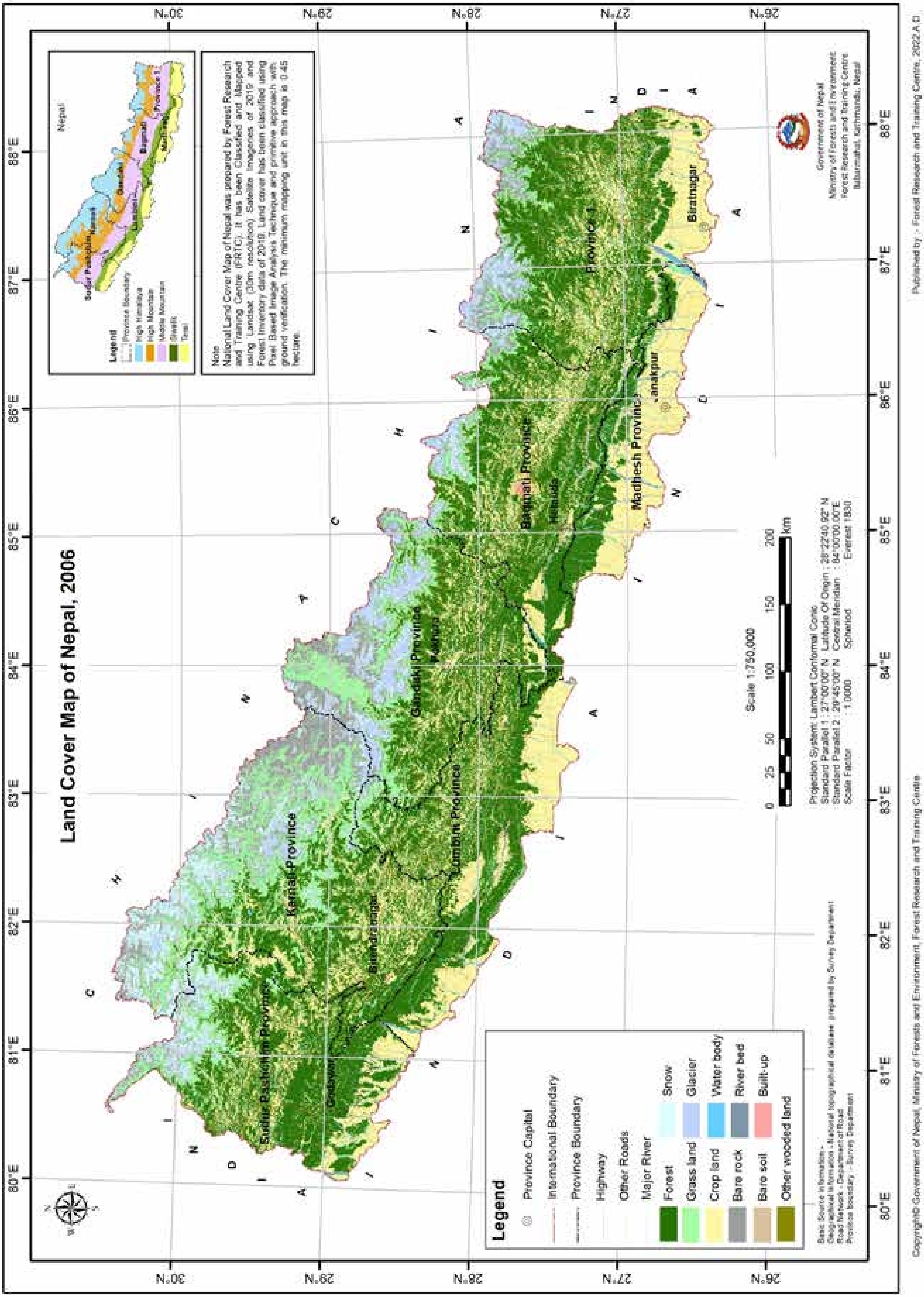
Land Cover Map of Nepal, 2006
Legend
Province Capital
International Boundary
Province Boundary
Highway
Other Roads
Major River
Forest
Grass land
Crop land
Bare rock
Bare soil
Other wooded land
Snow
Glacier
Water body
River bed
Built-up
Sudur Pashchim Province
Karnali Province
Lumbini Province
Gandaki Province
Bagmati Province
Madhesh Province
Province 1
Godawari
Birendranagar
Pokhara
Hetauda
Janakpur
Biratnagar
Nepal
Legend
Province Boundary
High Himalaya
High Mountain
Middle Mountain
Siwalik
Terai
Note
National Land Cover Map of Nepal was prepared by Forest Research and Training Centre (FRTC). It has been Classified and Mapped using Landsat (30m resolution) Satellite Imageries of 2019 and Forest Inventory data of 2010. Land cover has been classified using Pixel Based Image Analysis Technique and primitive approach with ground verification. The minimum mapping unit in this map is 0.45 hectare.
Scale 1:750,000
0 25 50 100 150 200 km
Projection System: Lambert Conformal Conic
Standard Parallel 1 : 27°00'00" N Latitude Of Origin : 28°22'40.92" N
Standard Parallel 2 : 29°45'00" N Central Meridian : 84°00'00.00"E
Scale Factor : 1.0000 Spheriod Everest 1830
Basic Source Information -
Geographical Information - National topographical database prepared by Survey Department
Road Network - Department of Road
Province boundary :- Survey Department
Government of Nepal
Ministry of Forests and Environment
Forest Research and Training Centre
Babarmahal, Kathmandu, Nepal
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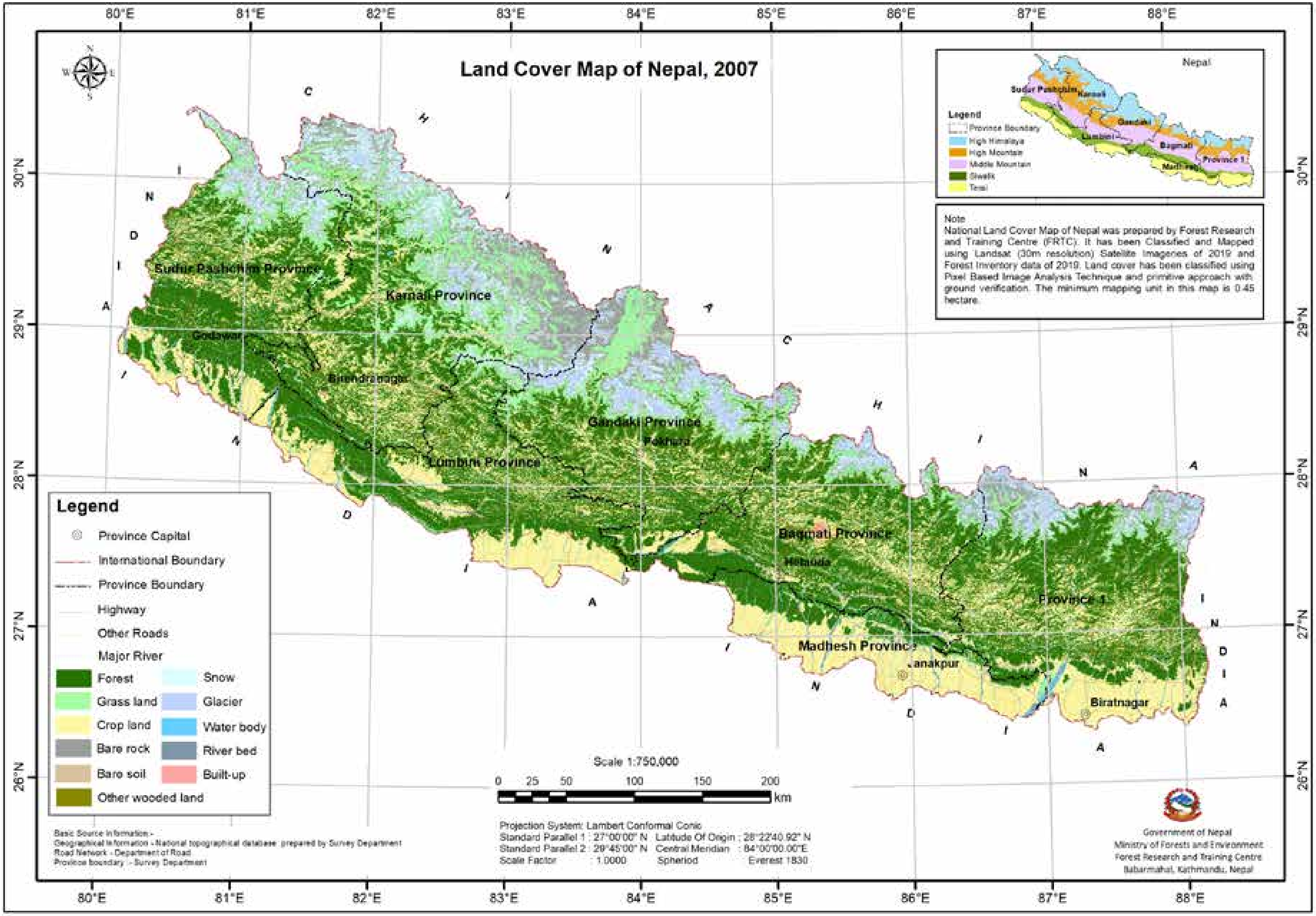

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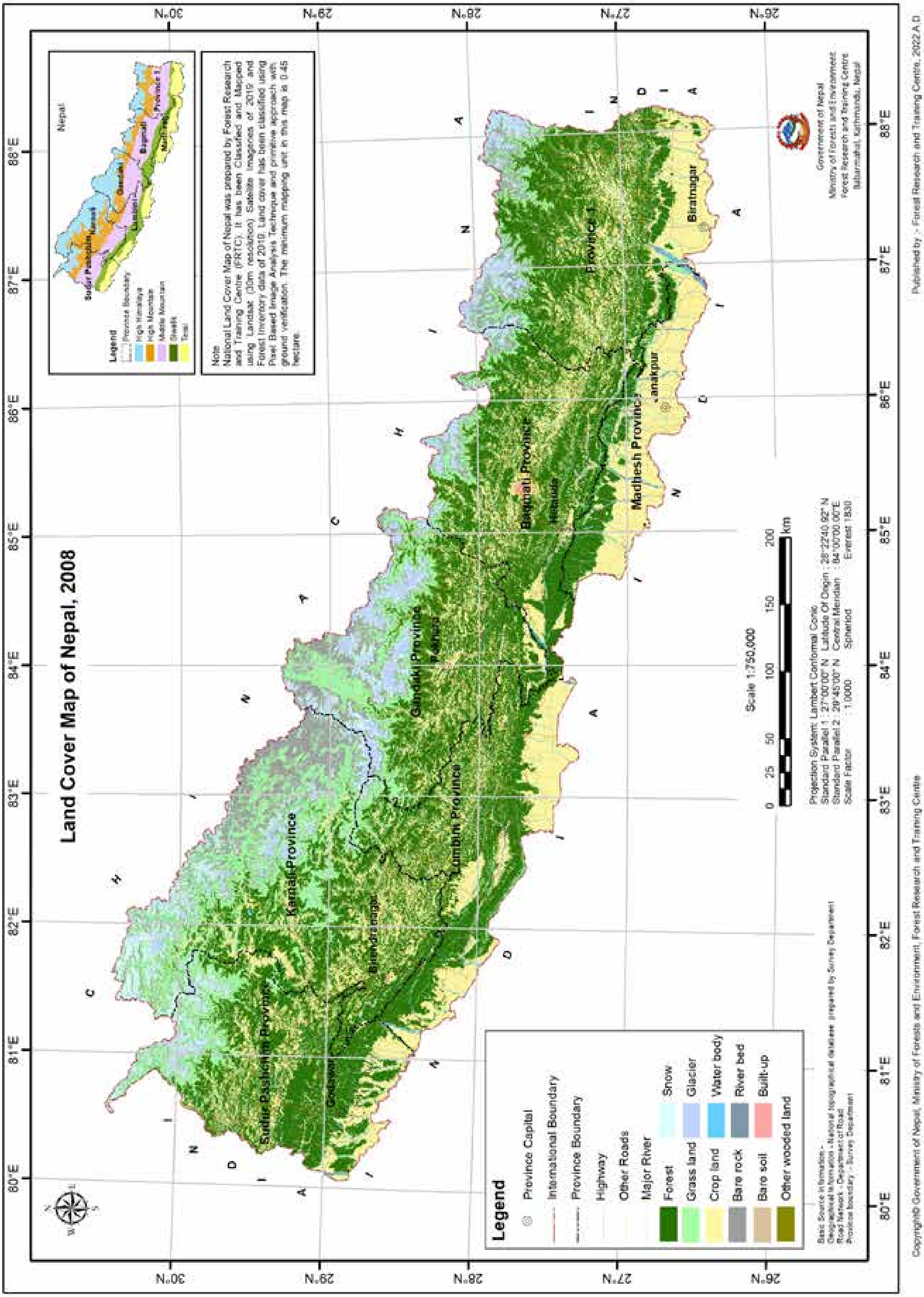

Land Cover Map of Nepal, 2008
Legend
Province Capital
International Boundary
Province Boundary
Highway
Other Roads
Major River
Forest
Grass land
Crop land
Bare rock
Bare soil
Other wooded land
Snow
Glacier
Water body
River bed
Built-up
Sudur Pashchim Province
Karnali Province
Lumbini Province
Gandaki Province
Bagmati Province
Madhesh Province
Province 1
Biratnagar
Janakpur
Hetauda
Pokhara
Birendranagar
Godawari
Scale 1:750,000
km
Projection System: Lambert Conformal Conic
Government of Nepal
Ministry of Forests and Environment
Forest Research and Training Centre
Babarmahal, Kathmandu, Nepal
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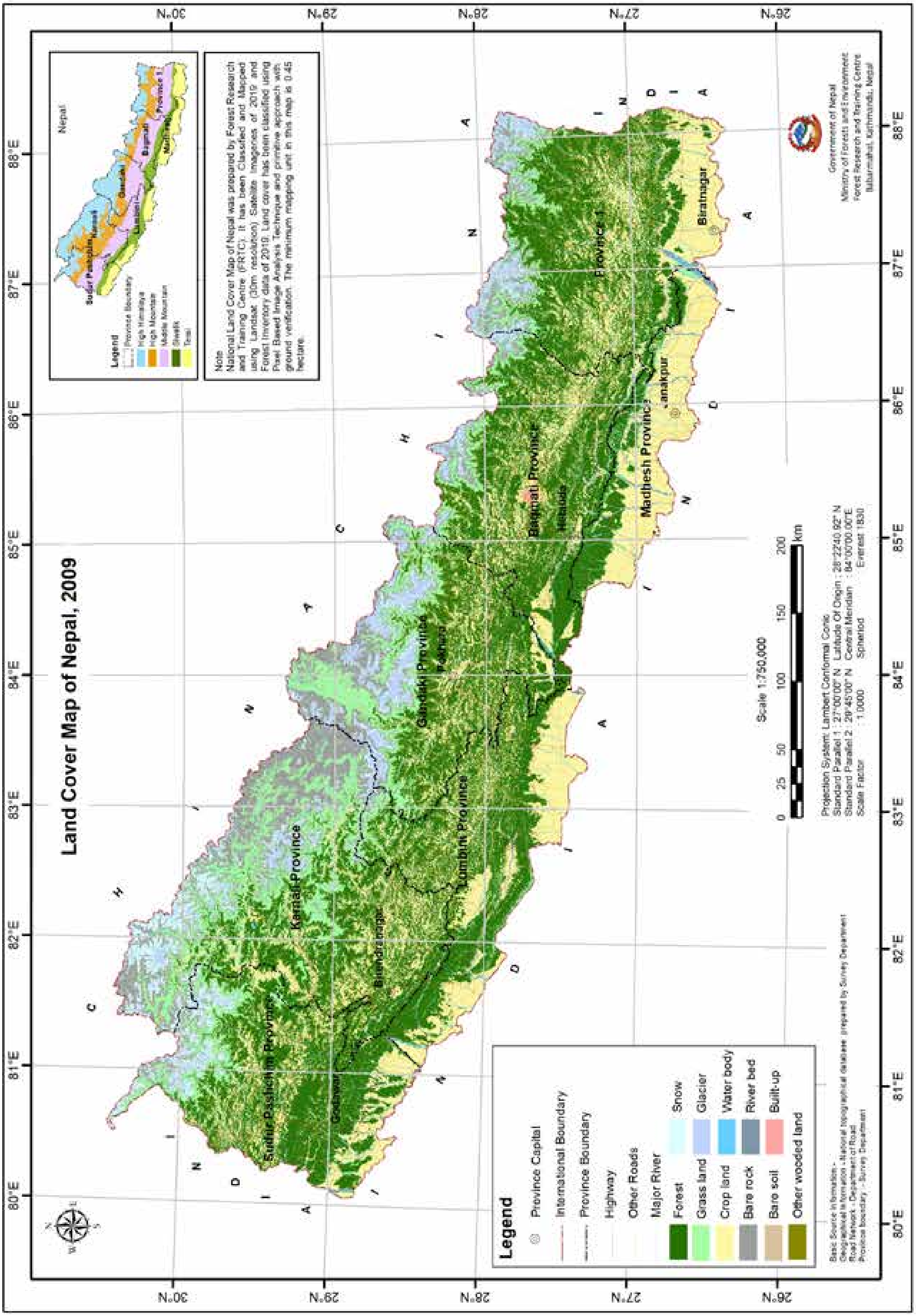

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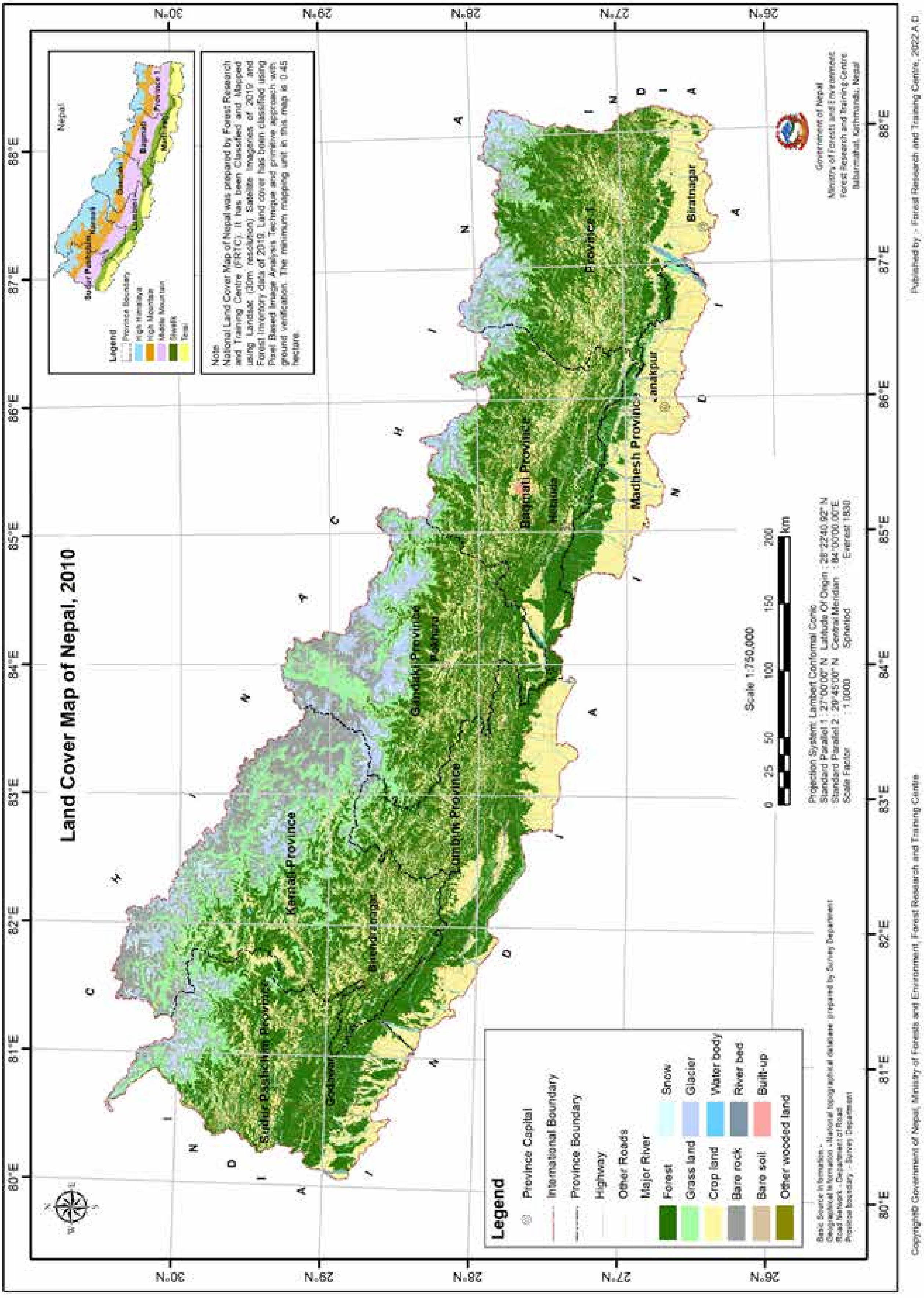

Land Cover Map of Nepal, 2010
Legend
Province Capital
International Boundary
Province Boundary
Highway
Other Roads
Major River
Forest
Grass land
Crop land
Bare rock
Bare soil
Other wooded land
Snow
Glacier
Water body
River bed
Built-up
Note
National Land Cover Map of Nepal was prepared by Forest Research and Training Centre (FRTC). It has been Classified and Mapped using Landsat (30m resolution) Satellite Imageries of 2019 and Forest Inventory data of 2010. Land cover has been classified using Pixel Based Image Analysis Technique and primitive approach with ground verification. The minimum mapping unit in this map is 0.45 hectare.
Nepal
Legend
Province Boundary
High Himalaya
High Mountain
Middle Mountain
Siwalik
Terai
Sudur Pashchim Province
Karnali Province
Lumbini Province
Gandaki Province
Bagmati Province
Madhesh Province
Province 1
Godawari
Birendranagar
Pokhara
Hetauda
Janakpur
Biratnagar
CHINA
INDIA
Scale 1:750,000
0 25 50 100 150 200 km
Projection System: Lambert Conformal Conic
Standard Parallel 1 : 27°00'00" N
Standard Parallel 2 : 29°45'00" N
Scale Factor : 1.0000
Latitude Of Origin : 28°22'40.92" N
Central Meridian : 84°00'00.00"E
Spheroid : Everest 1830
Basic Source Information
Government of Nepal
Ministry of Forests and Environment
Forest Research and Training Centre
Babarmahal, Kathmandu, Nepal
Published by :- Forest Research and Training Centre, 2022 A.D.
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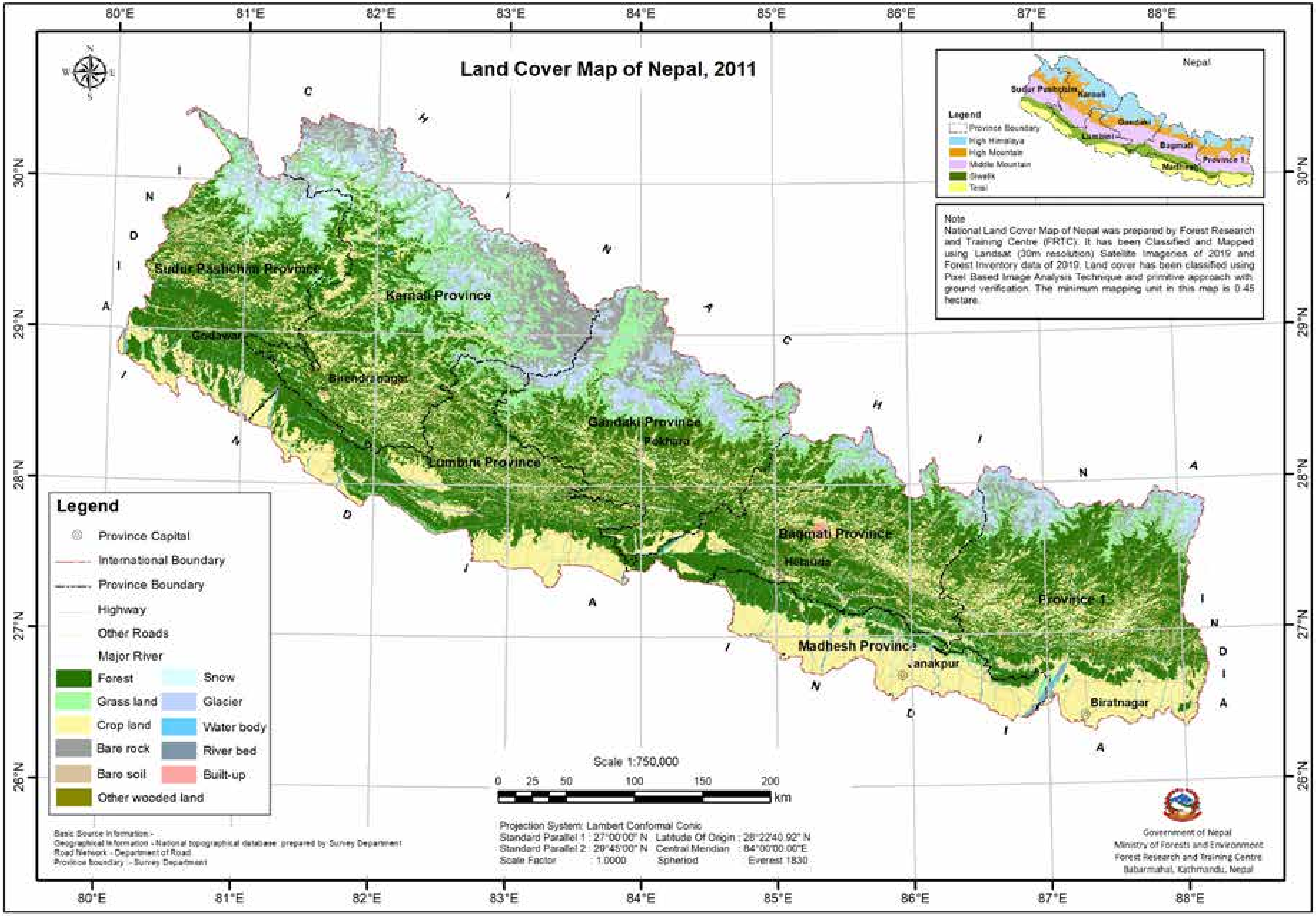
80°E
81°E
82°E
83°E
84°E
85°E
86°E
87°E
88°E
26°N
27°N
28°N
29°N
30°N



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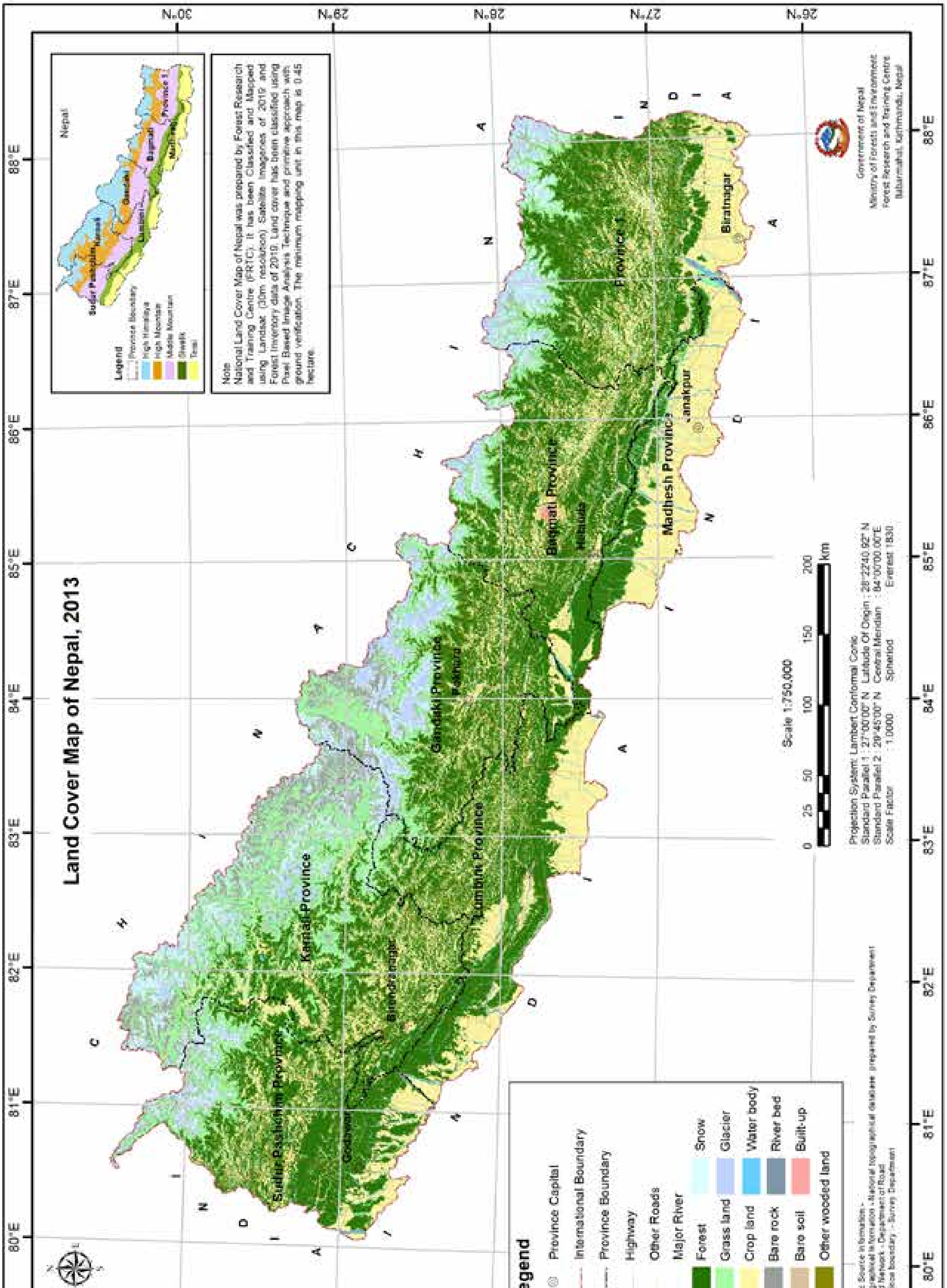

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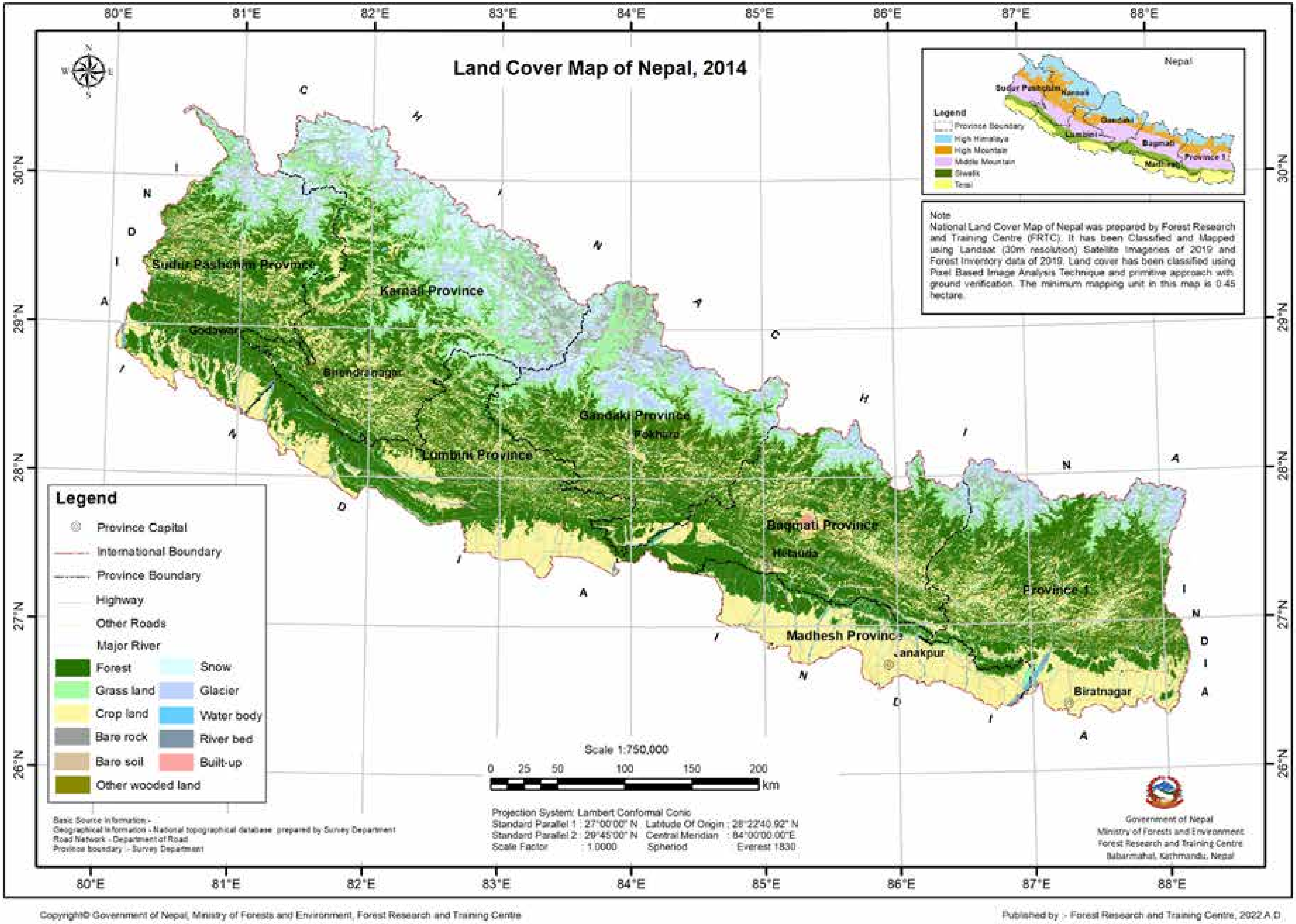
Land Cover Map of Nepal, 2014
Sudur Pashchim Province
Karnali Province
Gandaki Province
Lumbini Province
Bagmati Province
Madhesh Province
Province 1
Godawari
Birendranagar
Pokhara
Hetauda
Janakpur
Biratnagar
Nepal
Legend
Province Boundary
High Himalaya
High Mountain
Middle Mountain
Siwalik
Terai
Note
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Legend
Province Capital
International Boundary
Province Boundary
Highway
Other Roads
Major River
Forest
Grass land
Crop land
Bare rock
Bare soil
Other wooded land
Snow
Glacier
Water body
River bed
Built-up
Scale 1:750,000
0 25 50 100 150 200 km
Projection System: Lambert Conformal Conic
Standard Parallel 1 : 27°00'00" N Latitude Of Origin : 28°22'40.92" N
Standard Parallel 2 : 29°45'00" N Central Meridian : 84°00'00.00"E
Scale Factor : 1.0000 Spheriod Everest 1830
Basic Source Information -
Geographical Information - National topographical database prepared by Survey Department
Road Network - Department of Road
Province boundary :- Survey Department
Government of Nepal
Ministry of Forests and Environment
Forest Research and Training Centre
Babarmahal, Kathmandu, Nepal
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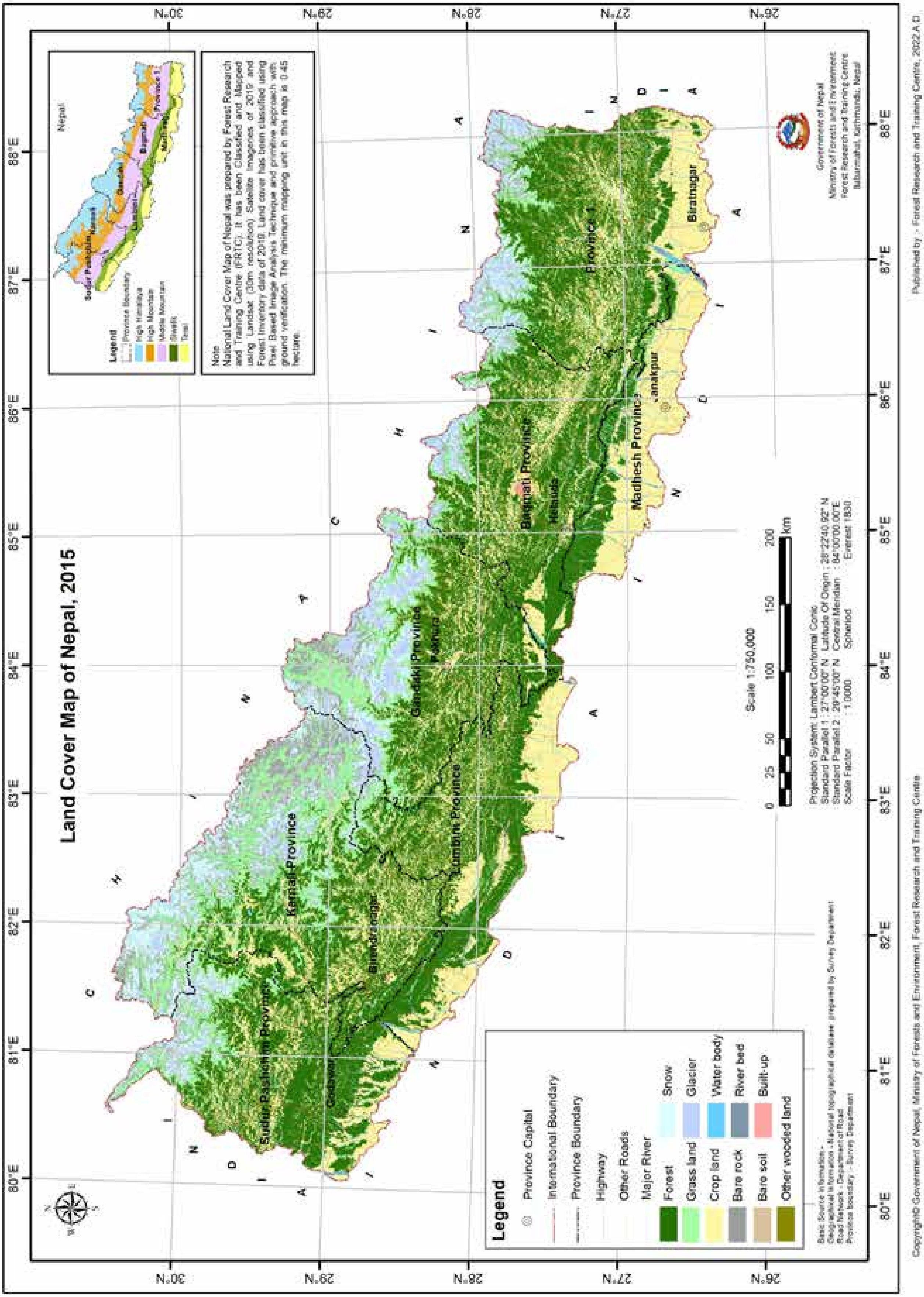

Land Cover Map of Nepal, 2015
Legend
Province Capital
International Boundary
Province Boundary
Highway
Other Roads
Major River
Forest
Grass land
Crop land
Bare rock
Bare soil
Other wooded land
Snow
Glacier
Water body
River bed
Built-up
Sudur Pashchim Province
Karnali Province
Lumbini Province
Gandaki Province
Bagmati Province
Madhesh Province
Province 1
Godawari
Birendranagar
Pokhara
Hetauda
Janakpur
Biratnagar
C H I N A
I N D I A
Note
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Nepal
Legend
Province Boundary
High Himalaya
High Mountain
Middle Mountain
Siwalik
Terai
Scale 1:750,000
0 25 50 100 150 200 km
Projection System: Lambert Conformal Conic
Standard Parallel 1 : 27°00'00" N
Standard Parallel 2 : 29°45'00" N
Scale Factor : 1.0000
Latitude Of Origin : 28°22'40.92" N
Central Meridian : 84°00'00.00"E
Spheriod : Everest 1830
Government of Nepal
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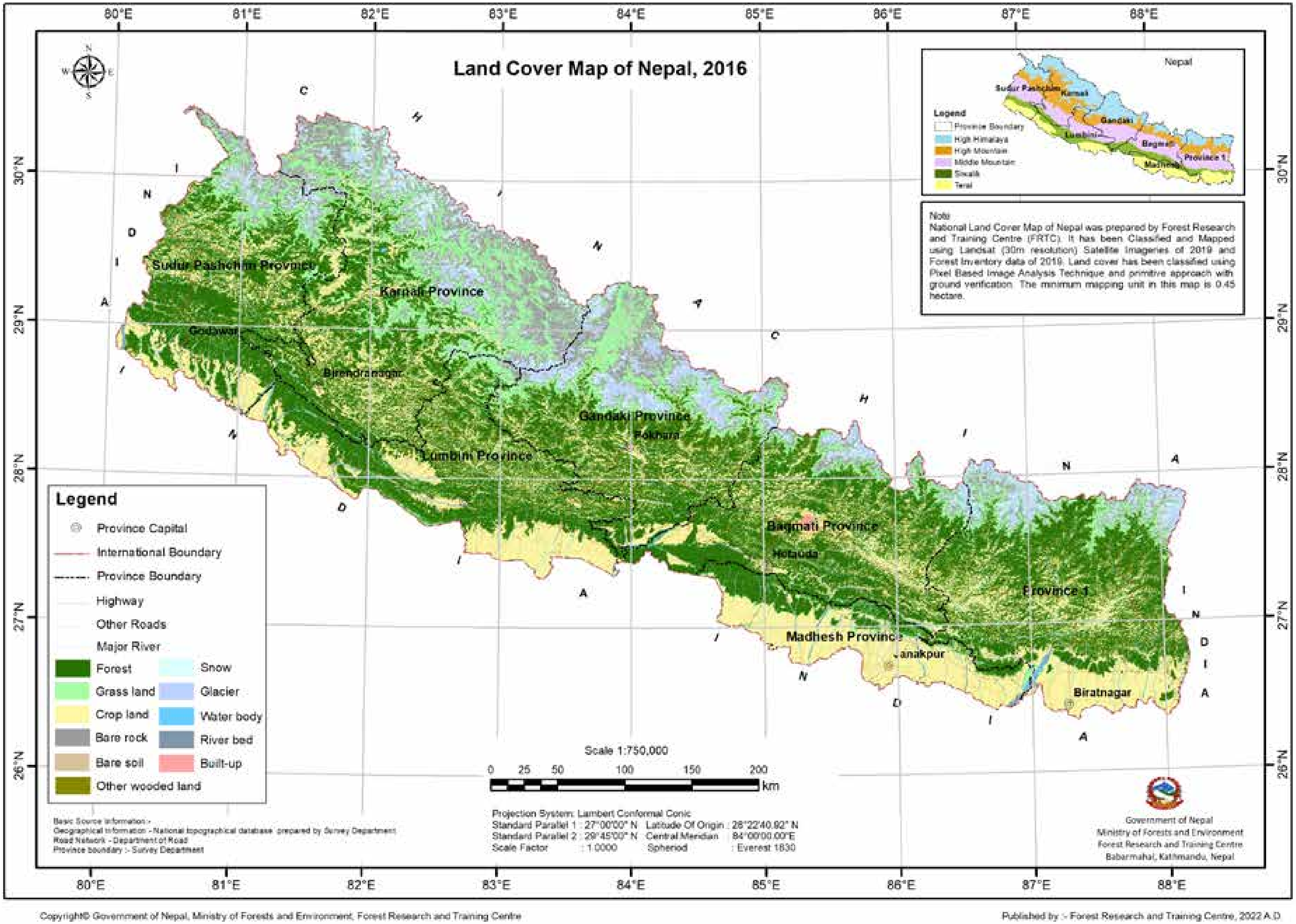
80°E 81°E 82°E 83°E 84°E 85°E 86°E 87°E 88°E
26°N 27°N 28°N 29°N 30°N



Land Cover Map of Nepal, 2016
Sudur Pashchim Province
Karnali Province
Gandaki Province
Lumbini Province
Bagmati Province
Madhesh Province
Province 1
Godawari
Birendranagar
Pokhara
Hetauda
Janakpur
Biratnagar
Legend
Province Capital
International Boundary
Province Boundary
Highway
Other Roads
Major River
Forest
Grass land
Crop land
Bare rock
Bare soil
Other wooded land
Snow
Glacier
Water body
River bed
Built-up
Nepal
Province Boundary
High Himalaya
High Mountain
Middle Mountain
Siwalik
Terai
Note:
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Scale 1:750,000
0 25 50 100 150 200 km
Projection System: Lambert Conformal Conic
Standard Parallel 1 : 27°00'00" N
Standard Parallel 2 : 29°45'00" N
Scale Factor : 1.0000
Latitude Of Origin : 28°22'40.92" N
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Basic Source Information :-
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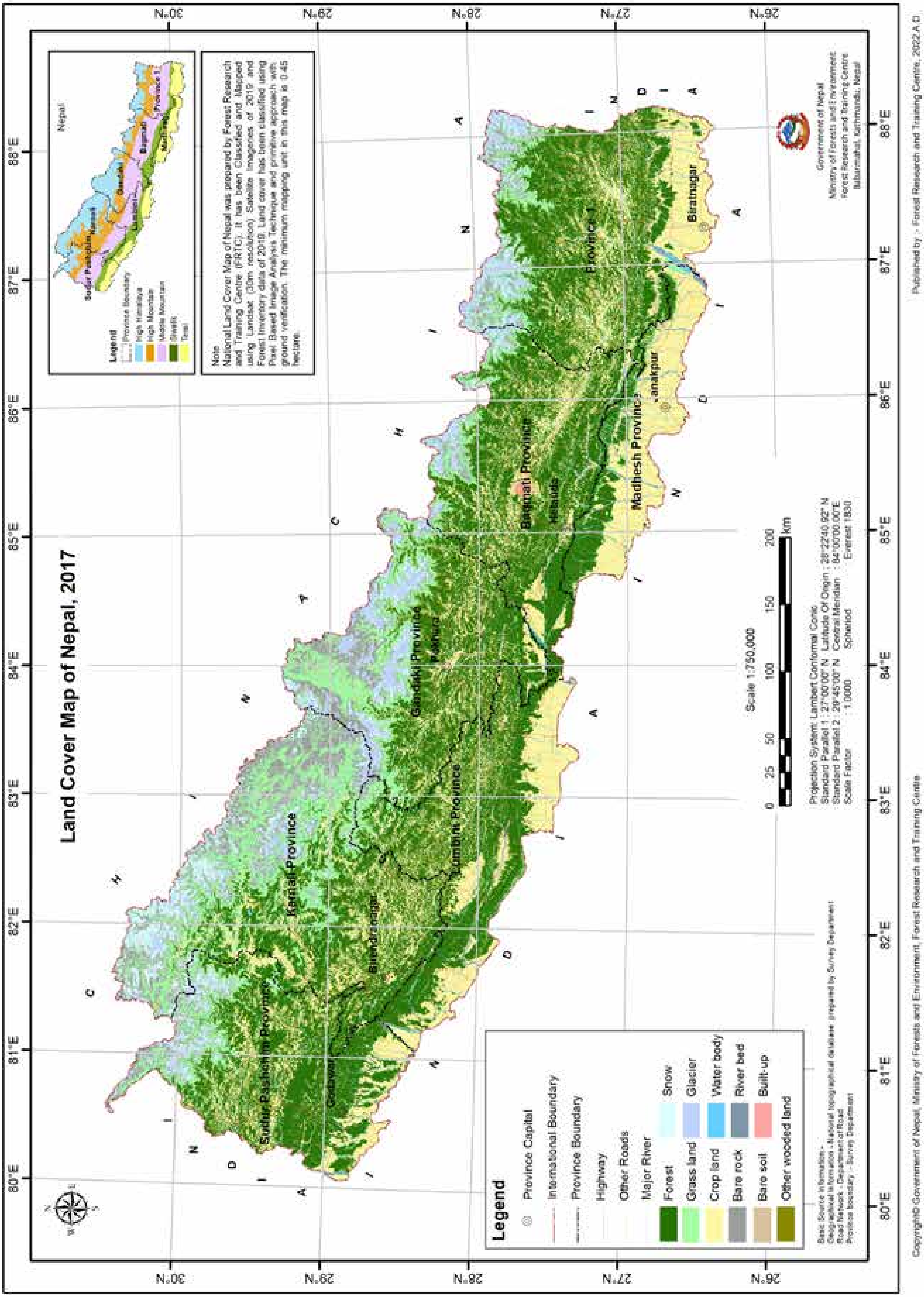

Land Cover Map of Nepal, 2017
Legend
Province Capital
International Boundary
Province Boundary
Highway
Other Roads
Major River
Forest
Grass land
Crop land
Bare rock
Bare soil
Other wooded land
Snow
Glacier
Water body
River bed
Built-up
Sudur Pashchim Province
Karnali Province
Lumbini Province
Gandaki Province
Bagmati Province
Madhesh Province
Province 1
Godawari
Birendranagar
Pokhara
Hetauda
Janakpur
Biratnagar
Scale 1:750,000
0 25 50 100 150 200 km
Projection System: Lambert Conformal Conic
Government of Nepal
Ministry of Forests and Environment
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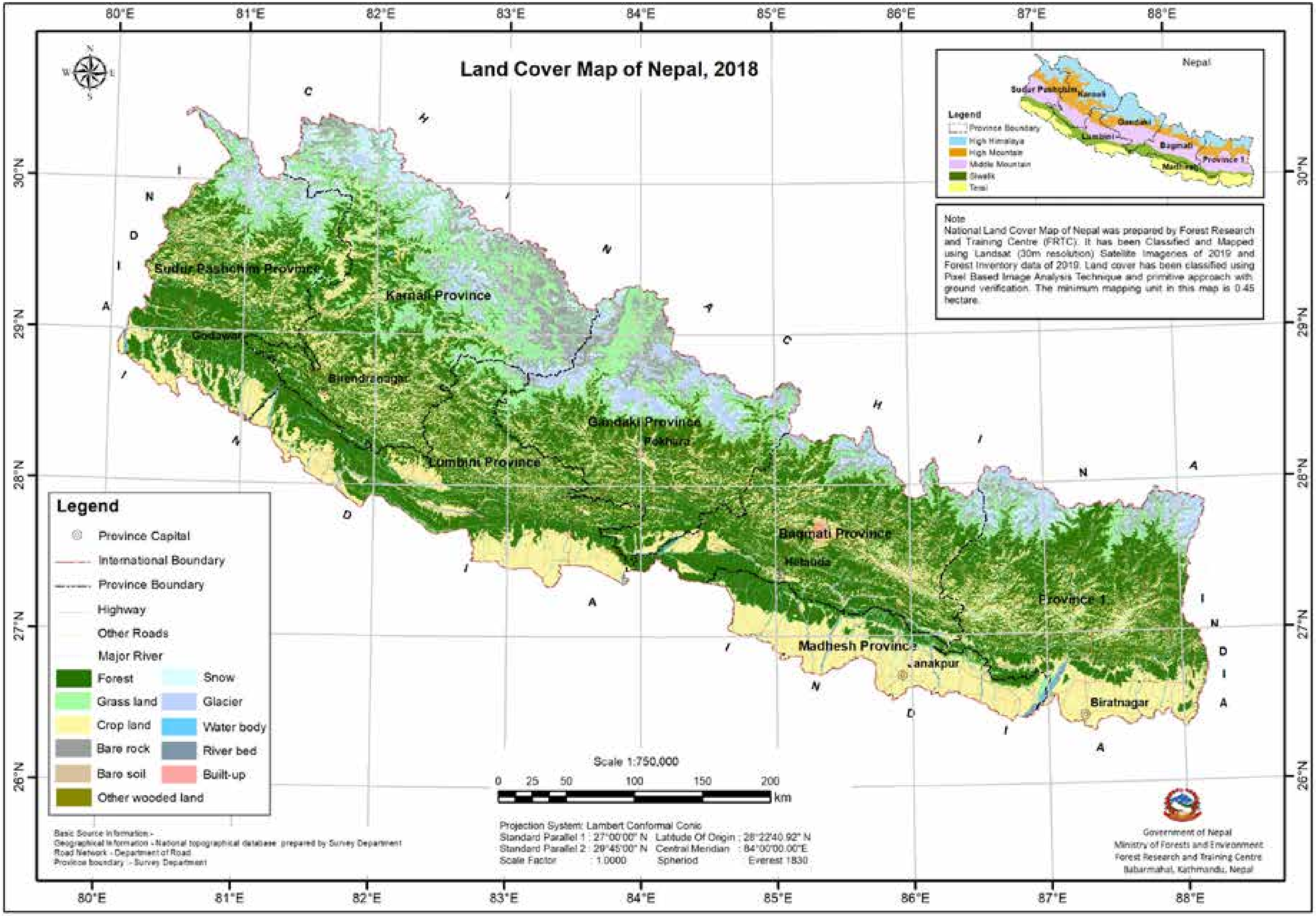

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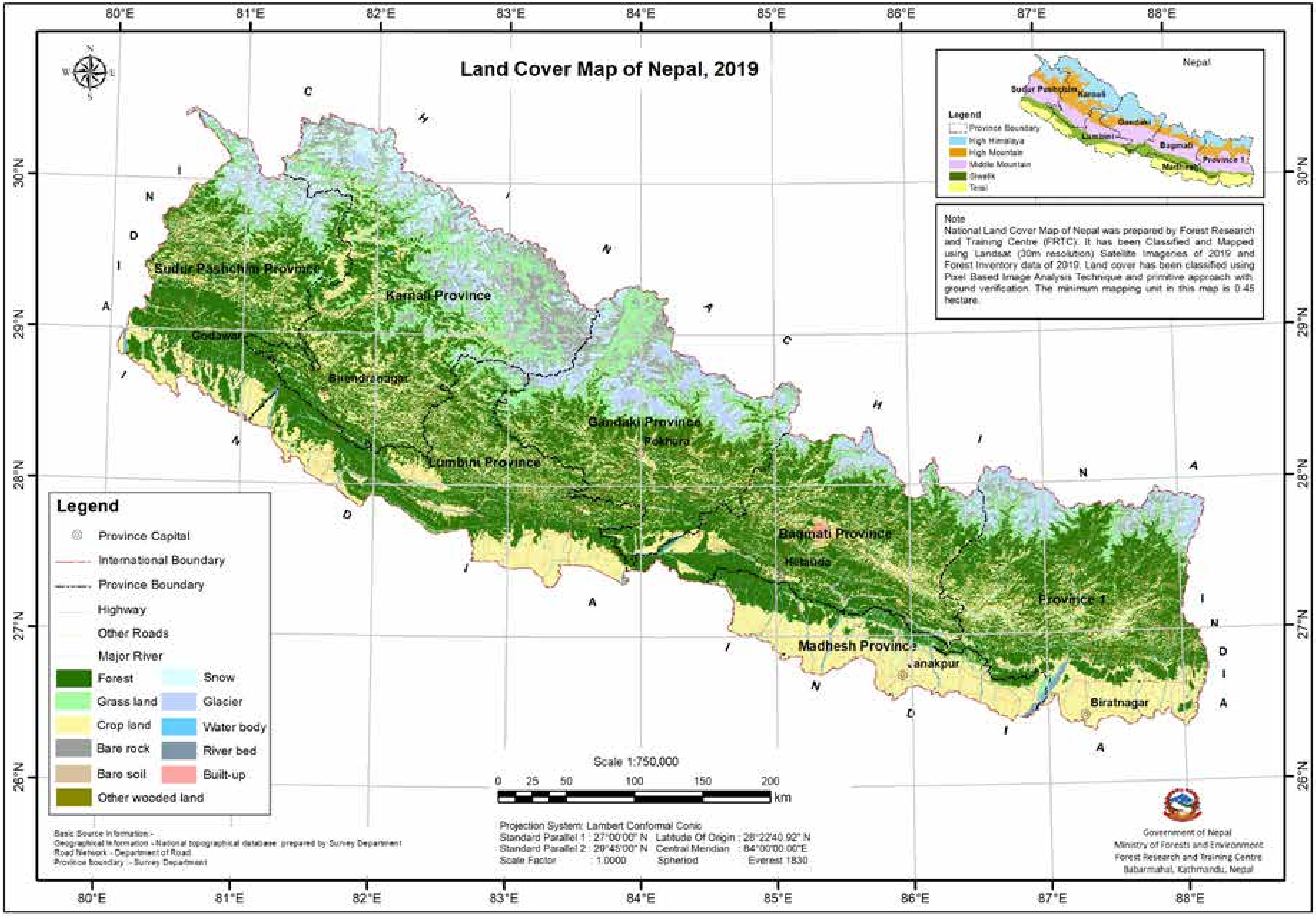

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