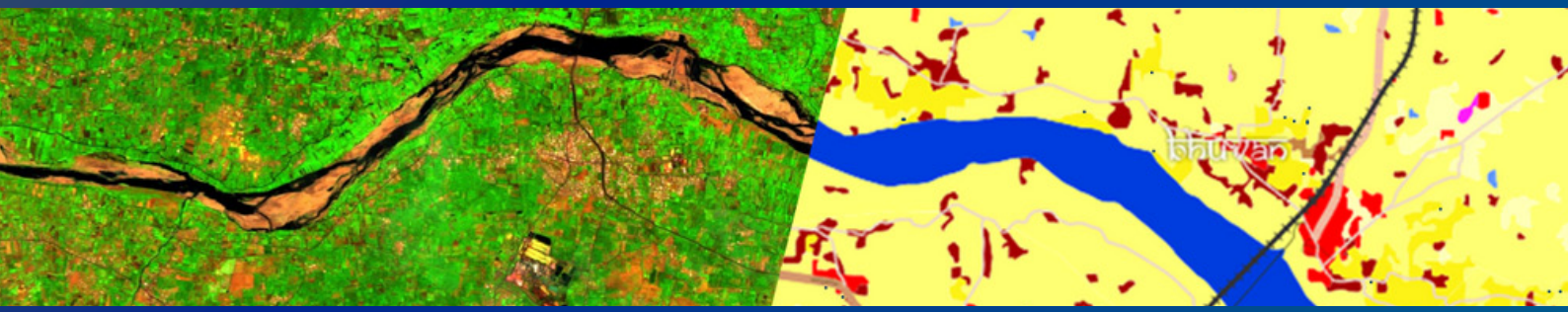
ANNUAL LAND USE AND LAND COVER ATLAS OF INDIA



Land Use & Cover Mapping and Monitoring Division
Soil Resources and Land Use Mapping and Monitoring Group
Remote Sensing Applications Area

NATIONAL REMOTE SENSING CENTRE

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Annual Land Use and Land Cover Atlas of India

National Remote Sensing Centre
Indian Space Research Organisation
Department of Space, Government of India
Hyderabad – 500037

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National Remote Sensing Centre
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Hyderabad

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15	**Abstract (with Keywords)**	Since 2004-05, NRSC and ISRO have been working on creating national geo-spatial database on land use and land cover for the entire country as part of the Natural Resources – Census (NR-CENSUS) initiative of NNRMS Programme of ISRO. The scope and objective of this project is to provide national LULC on an annual basis at 56m resolution (suitable for 1:250,000 scale). An 18 fold LULC classification system was used for mapping the entire country using multi-temporal and multi-sensor data. The broad methodology and steps involved are pre-processing of satellite imagery and subsequent image classification primarily using supervised classification with rule based integration. In addition to year wise LULC, season (Kharif and Rabi) and month (August, September, December and February) wise crop sown area layers are also prepared. Maps prepared from the annual LULC, Kharif and Rabi along with distribution of LULC class across various states were presented in the form of images and charts respectively. Analytical findings depicting the dynamics of Land Use and Land Cover during 17 cycles of mapping were presented as graphs. This project's outputs are crucial for policy making, monitoring land cover changes, managing natural resources, and serving as input for climate models and other research activities. Keywords: LULC, Kharif, Rabi, Double/Triple/Annual Crop, Built-up, Shifting Cultivation, Wastelands.			

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FOREWORD

The study and analysis of land use and land cover are essential in comprehending the intricate dynamics of the Earth's surface, particularly in an era marked by unprecedented global level changes. Observing and comprehending these transformations are realised now as a national imperative. Remote sensing, with its profound capability to capture, analyse, and interpret vast expanses of land from a distance, has revolutionized our perception of Earth's landscapes. In the Indian context, Land Use and Land Cover Mapping is regularly conducted using various satellite resolutions to meet this demand. It is timely to synthesize the knowledge amassed from efforts in this direction over last decade and a half.

I am delighted to introduce an Atlas that illustrates the outcomes of a long-term Earth Observation Application programme titled "National Land Use and Land Cover Assessment using Multi-sensor and Multi-temporal Data." This extensive program, conducted since the 2005-2006 period and spanning seventeen monitoring cycles, aims to assess the manifestation of Land Use and Land Cover patterns tied to the utilization of land resources each year. The information generated from this initiative is invaluable for policymakers, researchers, voluntary bodies, and environmentalists in their planning and decision-making processes.

This program was initiated as part of the Natural Resources Census Programme under the National Natural Resource Management System (NNRMS) of the Indian Space Research Organisation in 2004-05. The efforts have been led by the National Remote Sensing Centre (previously the National Remote Sensing Agency). The analysis incorporated multi-temporal IRS satellite data from the Advanced Wide Field Sensor (AWiFS), enabling the assessment of Land Use and Land Cover across eighteen distinct classes annually. Significantly, a substantial portion of these studies was conducted across various ISRO Centres, including Regional Remote Sensing Centres, IIRS, and NESAC, underscoring the collaborative national effort.

As we navigate an era characterized by rapid environmental changes and complex land use dynamics, this atlas will serve as a compass, guiding our understanding of land resources and facilitating sustainable development practices. It is my sincere hope that this atlas will act as a catalyst for informed decision-making, fostering responsible stewardship of our planet's invaluable resources.

(Prakash Chauhan)

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PREFACE

Land, as a finite resource, undergoes constant changes due to processes like rapid urbanization, evolving agricultural practices, and growing environmental concerns. These changes significantly impact the socio-economic fabric and the carrying capacity of ecosystems. The dynamic and intricate nature of Land Use and Land Cover (LULC) change involves a complex interplay between natural processes and multifaceted human interactions across social, economic, and ecological fronts. Accurate information on LULC and its changes is pivotal, forming the foundation for understanding trends related to national resources and assets, enabling informed decisions towards sustainable growth.

Land use and land cover maps serve as powerful tools for visualizing LULC changes. They are extensively utilized in developing and developed nations to enhance understanding in natural resource management, ensure food security, guide land use planning, and facilitate water management. The Department of Space has played a significant role in mapping the nation's assets through the National Natural Resources Management System (NNRMS). A national initiative to create land use and land cover data at a resolution of 56 meters commenced from the agricultural year 2004-05. Over the past 17 years, this project has consistently generated LULC data layers annually. These layers have been extensively utilized by various governmental, non-governmental, and academic entities, aligning with national commitments and scientific objectives, as well as governing aspects.

This atlas presents the noteworthy outcomes of the ISRO-DOS efforts in mapping and monitoring the country's land use and land cover dynamics over the past 17 years. A particular emphasis was placed on preparing crop sown areas in three seasons, influenced by factors such as irrigation infrastructure, rainfall, and residual moisture available.

I extend my heartfelt gratitude to all those who contributed to the creation of this atlas, acknowledging their steadfast dedication and unwavering perseverance in advancing our understanding of land use and land cover dynamics. May this atlas serve as an inspiration for further exploration, research, and proactive measures aimed at preserving the beauty and integrity of our landscapes for generations to come.

(K. Sreenivas)

ACKOWLEDGEMENT

Effort of continuing study of this nature aiming to understand and report national level spatial patterns using remote sensing over almost two decades is primarily due to persistent support given by highest level of leadership of our esteemed organisation. We would like to express sense of deep gratitude to Shri. P Somnath, Chairman, ISRO for supporting this pivotal programme serving varied interests of natural resource management in the country.

We are also grateful to Dr Prakash Chauhan, Director, NRSC for his keen interest in the theme and constant guidance and encouragement for the continuation of this study. We would like to thank continuous support and timely directives given by Dr Shantanu Bhatawdekar, Scientific Secretary, ISRO in carrying out Land Cover mapping studies.

Thanks are due to encouragement and advise provided by Dr Vinod Kumar , Associate Director, NRSC during the execution of this long term studies.

NRSC Team also would like to thank Directors of Forest Survey of India for sharing the Forest Cover Database for each of the relevant cycle of mapping. Kind cooperation and gesture of sharing extended is noteworthy.

Support given by the leadership at each of Regional Remote Sensing Centres during this long standing endeavour in terms of facilitating the study and enabling quality and scheduled deliveries are hereby acknowledged.

Role of NRSC Data Centre and Data Processing Area in providing Remote Sensing Dataset for each cycle is of paramount significance in this endeavour. We would like to acknowledge leadership for various value chains prevailed with Data Centre as well as Data Processing Area, NRSC are wholeheartedly acknowledged for their committed support and timely delivery of datasets. Support provided by Map Records facility in terms of valuable spatial reference for this project related information system is also acknowledged herewith.

Such an effort of studies spanning over eighteen years are not possible without the cooperation, guidance and appropriate support of various Areas/Groups/Divisions/Sections/Facilities of NRSC. We would like to express heartfelt gratitude to relevant members of all entities.

Annual LULC Study Team

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Acronyms

AWiFS	Advanced Wide Field Sensor
DEM	Digital Elevation Model
DN	Digital Number
DOS	Department of Space
FAO	Food and Agriculture Organization
ISRO	Indian Space Research Organisation
LULC	Land Use and Land Cover
NASA	National Aeronautics and Space Administration
NGOs	Non-Governmental Organizations
NICES	National Information System for Climate Sciences
NNRMS	National Natural Resource Management System
NRR	Natural Resource Repository
NRSC	National Remote Sensing Centre
SAR	Synthetic Aperture Radar
SDG's	Sustainable Development Goals
SRTM	Shuttle Radar Topography Mission
TOA	Top of Atmosphere
D/T/A Crop	Double/Triple/Annual Crop
UNESCO	United Nations Educational, Scientific and Cultural Organization

Executive Summary

Land use and land cover monitoring is the essential practice of observing, assessing, and recording the transformations that occur on Earth's surface. This systematic examination of how the land is utilized and its associated characteristics offers invaluable insights into the evolving dynamics of our environment. From urban development to agricultural expansion and natural resource management, understanding these changes is pivotal for informed decision-making, sustainable planning and effective environmental conservation. Land Use and Land Cover (LULC) analysis stands as a pivotal facet for the meticulous assessment of natural resources and systematic planning at periodic intervals. Capitalizing on the potential of Remote Sensing data, the National Remote Sensing Centre (NRSC) annually undertakes a comprehensive national-level Land Use and Land Cover project as part of its contributions to the National Natural Resource Management System since year 2005-06 onwards. The primary objectives of this endeavor encompass the following: 1) Expedited evaluation of the National-Level Annual LULC leveraging multi-temporal and multi-sensor satellite data, 2) Compilation of crop data for the Kharif and Rabi seasons upon their culmination, and 3) Generation of derivative products essential for the programme of National Information System for Climate & Environment Studies (NICES). To achieve these objectives, NRSC has formulated a rigorous land use classification framework encompassing 18 distinct classes for mapping the National LULC at 56m resolution commensurate with 1: 250,000 sacle.

Multi-temporal and multi-sensor satellite imagery undergoes meticulous pre-processing to establish surface reflectance, followed by classification through the implementation of a diverse array of semi-automated rule-based techniques. The outcome of this project encompasses preparation of geo-spatial dataset on 56m resolution 1) Annual National Land Use and Land Cover data for India, 2) Annual Kharif and Rabi crop data, 3) Monthly Kharif sown area for August and September, 4) Monthly Rabi sown area for December and February, and 5) Reprocessed LULC inputs requisite for NICES and meteorological forecasting models.

Commencing its journey in 2005-06 and persevering till the present fiscal year 2022-23, the project has completed 17 annual cycles of LULC and seasonal crop assessment. These datasets are visually represented in the form of maps, and the distribution of classes within each Indian state is also presented graphically. These long-term temporal datasets assume paramount significance in a myriad of research and planning ventures. Conducting an exhaustive analysis of 17 cycles of Land Use and Land Cover (LULC) records spanning from 2005 to 2023, significant patterns within major land use and land cover classes have been discerned. The analysis unfurls a discernible positive correlation between crop area and fallow land. Over these cycles, fallow land has consistently dwindled, while the crop area has exhibited consistent growth. Over the past 17 years, Kharif and Rabi cropland has expanded by 46.06% and 35.23% respectively, as fallow land diminished by 45.19%. Additionally, double/triple/annual cropping areas have increased by 82.22% and built-up land shows a modest increase with an overall growth of 30.77% in this period. Water resource indicated by minimum waterbody surface showed an increase by 146 % over this period. Whereas, shifting cultivation representing a subsistence farming practice, demonstrated a gradual ascent until 2016-17, after which it witnessed a decline. These findings hold profound relevance for the formulation of development programs, monitoring land cover dynamics, natural resource management, and fostering research across various governmental departments.

1. Introduction

1.1 Background

In order to make decisions, a contemporary country like India with a diverse flora and fauna has to have access to adequate information on a number of complicated, interrelated areas of its activities. Land Use and Land Cover is one such outcome of complex interrelationship between human and earth development process. Although the terms "Land Use" and "Land Cover" are often used interchangeably, their actual meanings are quite distinct. Land cover is the physical manifestation of these relationship whereas land use refers to the purpose the land serves, for example agriculture, settlements, mining etc.

According to Food and Agriculture Organization (FAO), the land use is defined as the total of arrangement activities and inputs that people undertake in certain land cover types. Land cover refers to observed physical and biological cover of the earth's land. Land is covered by various forms such as vegetation, grassland, scrubs, water bodies, bare soil etc. As the country works to address the issues like haphazard, uncontrolled development, declining environmental quality, loss of prime agricultural lands, destruction of significant wetlands and loss of aquatic and wildlife habitat, knowledge of accurate and current land use data has become more crucial. Reliable information about land usage is essential for governmental and commercial organizations, to understand what is happening and to formulate effective strategies for their own future actions.

The classification of land use and cover, based on remote sensing data is crucial for understanding and managing our changing environment. Remote sensing data offers several advantages for this task. Satellite sensors capture data across various spectral bands, enabling the identification of different land cover types based on their unique spectral signatures. This capability facilitates to discriminate between different land features and creation of accurate land cover maps, which are vital for urban planning, resource management, and environmental monitoring. Remote sensing data can be acquired at regular intervals, enabling temporal analysis by comparing multiple images taken over time, land cover changes can be detected, such as deforestation, urban expansion, or agricultural shifts. These temporal datasets enable the assessment of land

use dynamics and the evaluation of the effectiveness of land management policies and practices. Moreover, remote sensing data provides valuable ancillary information for land use and cover classification.

The framework or approach used to uniformly categories and give labels to various land cover or land use types based on the examination of remote sensing data is referred to as land use and cover classification system (Anderson, et al. 1976). The choice of classification system depends on the individual application and analytic goals. There are many classification systems used in remote sensing. The classification system for remote sensing imagery provides a structured framework for analyzing and categorizing land cover or land use types based on the spectral information captured by remote sensing sensors. These systems enable a better understanding of the Earth's surface, support decision-making processes, and facilitate the monitoring and management of natural resources. Overall, land use and land cover data are versatile resources that support a wide range of applications, including urban planning, environmental monitoring, agriculture, natural resource management, climate change analysis, risk assessment, and policy development. The recent National Geospatial Policy in The Gazette of India on December 28, 2022 (CG- DL-E-28122022-241463) has adopted 14 National Fundamental Geospatial Data Themes for the development of the country's integrated Geospatial Infrastructure and will support the Sustainable Development Goals (SDGs). "Land Cover and Land Use" is listed as one of the National Fundamental Geospatial Data Themes. Department of Space (National Remote Sensing Centre) along with the Ministry of Environment, Forest & Climate Change (Forest Survey of India) are identified as the nodal ministry/department for creating Land Cover and Land Use theme.

1.2 Project Overview

Considering the potential of Remote Sensing satellite data a national project on creating National Level Land Use/ Land Cover on annual basis is taken up as a part of Natural Resource Census (NRC) activity under National Natural Resource Management System (NNRMS) of Department of Space (DOS), Government of India, with an objective to undertake "Rapid assessment of National Level LULC on 1:250,000 scale using Multi-temporal AWiFS data starting from the year 2004-05". In the subsequent cycles, Multi-sensor satellite data are also used as a substitute for AWiFS data in the clouded region

and to improve the classification accuracy. An 18-fold LULC classification system suitable for creating LULC for the entire country is adopted in this project. Final output product is in raster format and are being disseminated among various users, using Bhuvan Web portal. So for 17 cycle of National LULC along with seasonal (Kharif and Rabi) and monthly (August, September, December and February) crop sown area have been done. Theses output products are being utilized for many national and regional level research activities under taken by various government organisations, academic institutions, NGOs, individuals etc.

1.3 Objective

Major objectives of this project are as follows

- Rapid assessment of National Level Annual Land Use Land Cover using multi-temporal satellite data.
- Reporting of Kharif and Rabi seasonal crop area at the end of season.
- Generation of derivative products required for NICES program.

1.4 Deliverables

The following products are the outcome of the project

- Annual National Land Use and Land Cover data for India at 1:250,000 scale with statistics.
- Annual Kharif and Rabi Crop data and statistics.
- Monthly Kharif crop data for August and September with Statistics report.
- Monthly Rabi crop data for December and January with Statistics report.
- Reprocessed LULC inputs required for NICES and weather forecast models.

2. Study Area

The study area comprises of entire India which is located in the southern part of Asian continent. With nearly 1.4 billion inhabitants, it is the most populated nation in the world and the seventh- largest country by land area. The country lies to the north of the equator between 6°44′N and 35°30′N latitude and 68°7′E. and 97°25′E longitude, with a land area of 32,87,260 sq.Km. Its land border measures 15,200km (9,445 miles), and its coastline

measures 7,516.5 km. India has a range of landscapes starting from the north it is bounded by the Himalayan mountain range extends over 2500 Km from Jammu &Kashmir to Northeast part of the country. The Indo-Gangetic plains are having high deposits of alluvial soil which are more fertile and suitable for cultivation. The western part is covered with the Thar Desert, which is an arid region. The Central Highlands are composed of three main plateaus – the Malwa Plateau in the west, the Deccan Plateau in the south, (covering most of the Indian peninsula); and the Chota Nagpur Plateau in Jharkhand towards the east. The Western Coastal Plain is a narrow strip of land sandwiched between the Western Ghats and the Arabian, receives the first rainfall in the monsoon season which begins in the mid of June. The Eastern Coastal Plain is a wide stretch of land lying between the Eastern Ghats and the Bay of Bengal mainly composed of delta suitable for agriculture. The North-Eastern part of India is mostly of hilly terrain with dense evergreen-woodlands. This place receives high to very high rainfall during the monsoons. India is having two offshore islands, Andaman and Nicobar islands in the Bay of Bengal and Lakshadweep islands in the Arabian Sea. Coral reefs are present in the large extent along the coast of the islands. The Study area map is presented in figure 1.

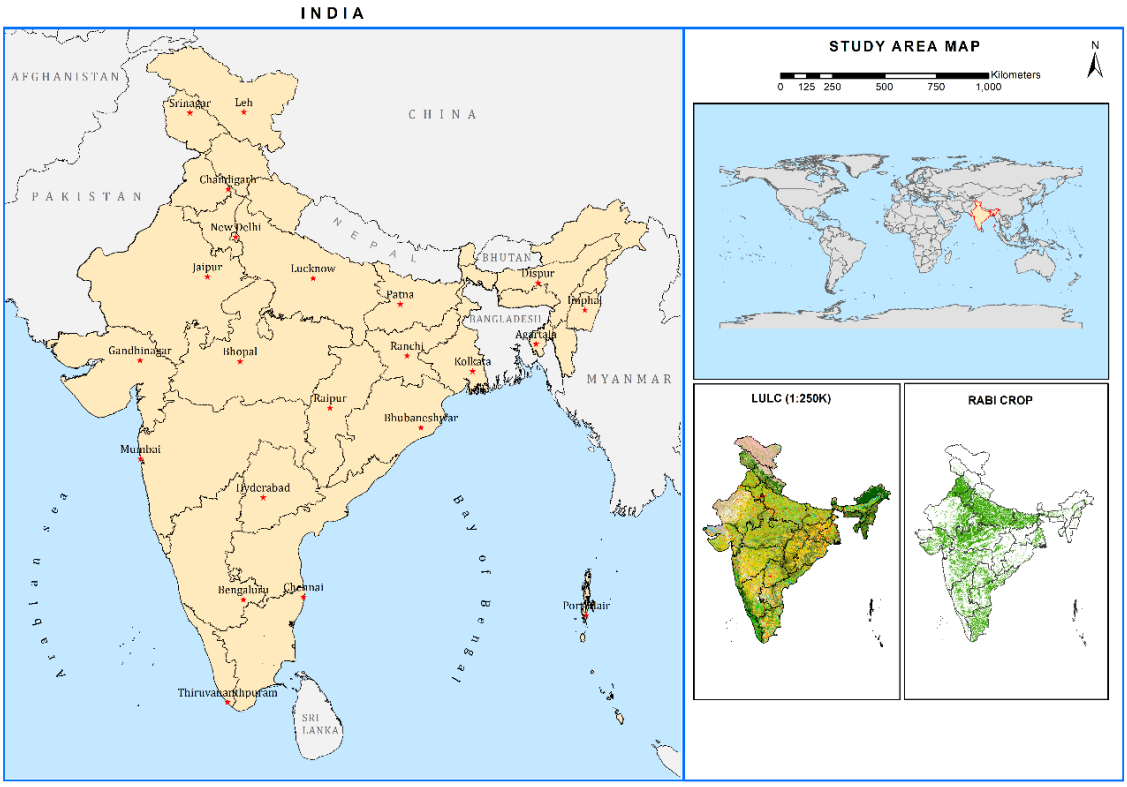

Figure 1 - Study area map

3. Methodology

The creation of land use and land cover under this project involves the utilization of multi-temporal and multi-sensor satellite data. Prior to classification, requisite pre-processing is conducted. The classification system employed in this project comprises six primary types and 18 sub-divisions (detailed in annexure –II). Figure 2 illustrates the datasets utilized and the methodology implemented.

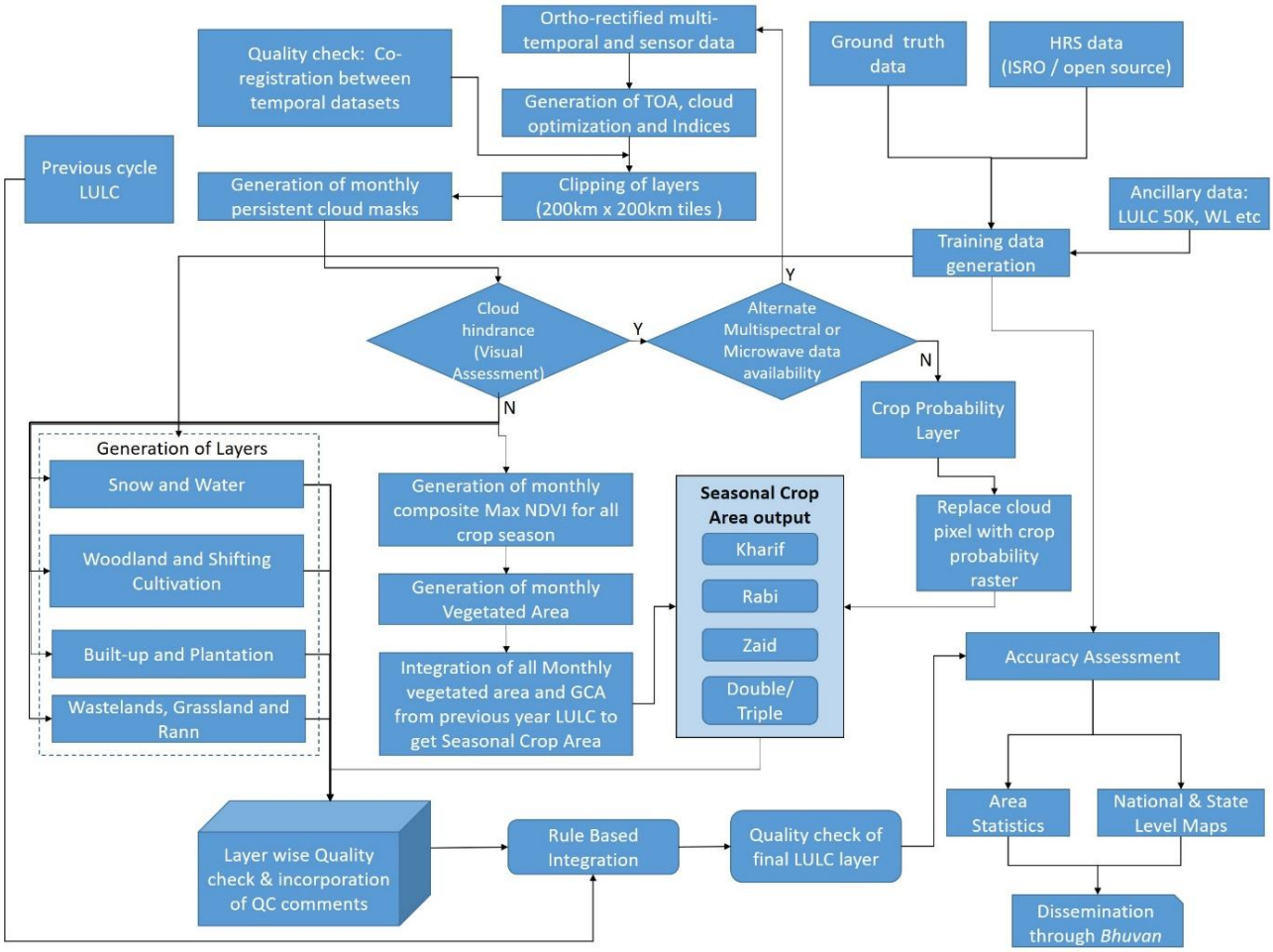

Figure 2- Methodology Flowchart

3.1 Data Used

The key crop seasons of Kharif and Rabi were covered by the multi-temporal satellite data primarily from AWiFS sensor from a series of Resourcesat satellites have been used in this experiment acquired between June to May of an agricultural calendar year (Asra, et al. 2015). In order to fill in the data gaps in overcast regions, additional multispectral, microwave data from satellites like Landsat and Sentinel 1, sentinel 2A and 2B, SRTM DEM, NASA DEM and other sensors are also used to determine topographic factors (Brown et al. 1993). The satellite datasets alone are not enough to effectively distinguish the spectrally overlapping land cover constituents; ancillary databases are also required. As legacy data, spatial forest and wasteland data that are available on a national basis are employed. The 1:50,000 scale LULC maps created by NRSC are utilized as supplemental data wherever needed. The ortho-corrected, high resolution satellite data is resampled to a resolution of 56 m and utilized as the primary reference data to ensure geometric compatibility. State level maps and zonal statistical analysis are produced using geo-referenced state boundaries and meteorological zones.

3.2 Data Pre-Processing

The image was provided in raw format (digital values were not geometrically corrected), hence it requires radiometric and geometric modifications. Two processes made up the radiometric correction: (i) sensor calibration (which converted digital numbers into radiance values); and (ii) reflectance estimation (which transformed radiance values into reflectance values). The various parameters needed for estimating spectral reflectance are: maximum and minimum radiances in the satellite sensor bands, mean solar exo-atmospheric irradiances, image acquisition time, solar angles (zenith and azimuth) and mean Earth–Sun distance. Ortho-rectification and TOA correction were carried out onto multi-temporal optical data. From the information, each sensor-specific calibration constants are retrieved and utilized to produce the TOA for the corresponding satellite data (Sreenivas et al. 2015). To obtain a cloud-free mosaic, cloud identification and masking are performed. Slant range to ground range processing is done while using microwave SAR data. Utilizing the radar equation and the appropriate sensor parameters, radiometric calibration was performed to convert the DN value to the backscatter

coefficient. The proper filters have been used to remove the speckles. These previously processed optical and microwave data serve as the categorization input.

3.3 Classification System

The land use and land cover classification have been done by employing an 18-fold classification system developed for the project by utilizing multi-temporal and multi-sensor satellite data. Brief description of this 18-fold classification system is elucidated as follows.

3.3.1 Built-up Land

Built- up areas are characterized by substitution of the original (semi-) natural cover or water surface with an artificial, often impervious, cover. This artificial cover is usually characterized by long cover duration (Di Gregorio and Jensen, 2004). The term "built-up area" refers to an area with buildings (roofed structures), paved surfaces (roads, parking lots), commercial and industrial sites (ports, landfills, quarries, runways), and urban green areas (parks, gardens).

3.3.2 Crop Land

Crop lands may be defined as those lands which are cultivated to produce food crops and related activities. Crop lands are primarily used for production of different type of crops for commercial and consuming purpose. In the classification system used here, there are four classes belongs to the crop land i.e. Kharif, Rabi, Zaid and Double/Triple/Annual crop land.

Kharif Crop– These are areas which are cultivated between June/July to September/ October coinciding with SW monsoon season. It is associated with rain- fed crops under dry land farming with limited or no irrigation and areas of rain- fed paddy and other dry crops.

Rabi Crop– These areas are areas cultivated between November / December to February / March. It is associated with areas under assured irrigation irrespective of the source of irrigation. However, Rabi cropped areas also occur in rain-fed regions, under residual soil moisture conditions especially in black soil areas with high rainfall during Kharif season.

Zaid Crop – These are the areas that are cropped April - May (summer) which are mostly associated with irrigated areas with fertile soils, confined to plains/delta areas.

Double Crop/Triple/Annual Crop– Double/Triple crop land are the area where crops are sown and harvested twice/thrice in one crop year. Annual crop are perennial and grow throughout the year such as sugarcane.

3.3.3 Current Fallow Land

An agricultural system with an alternation between a cropping period of several years and a fallow period (Ruthenberg,1980). These are the lands, which are taken up for cultivation but are temporarily uncultivated, un-cropped for one or more season. Due to drought or inadequate rainfall cropland areas may get converted into fallow land for a particular year.

3.3.4 Plantation/Orchard

These are the regions where tree crops have been planted in agriculture land using agricultural management methods. Plantation/Orchard also comprise the regions of land use systems and practises where, for ecological and financial reasons, the cultivation of herbs, shrubs, and vegetable crops is purposefully combined with agricultural crops, typically in irrigation settings. These areas can be distinguished from agricultural land, Plantation/Orchard may also includes as follows:-

- Permanent commercial crops - Coffee, mulberry, tea, rubber etc., which are normally grown in the hilly regions and are closely associated with forest cover.
- Abandoned orchards which still preserve characteristic alignments.
- Fruit, orchards of apples, pears, plums, apricots, peaches, cherries, figs etc.,
- Ligneous crops - Chestnut, walnut, almond, hazel, pistachio groves.

3.3.5 Woodland

The term woodland is used to refer to land with a tree canopy cover of more than 10 percent and area of more than 0.5 ha. Woodland are determined both by the presence of trees and the absence of other predominant land uses. The trees should be able to reach a minimum height of 2m. It consists of three woodland classes i.e. Evergreen / Semi-evergreen woodland, deciduous woodland and degraded woodland.

Evergreen/Semi-evergreen Woodland- This category comprises of trees(>2m tall), which are predominantly remain green throughout the year. It includes both coniferous and tropical broadleaved evergreen species. Semi- evergreen is a woodland type that includes a combination of evergreen and deciduous species with the former dominating the canopy cover.

Deciduous Woodland - These are the woodland types that are predominantly composed of tree (>2m tall) species, which shed their leaves once a year. It may also include tree clad area with tree cover lying outside the notified forest boundary areas that are herbaceous with a woody appearance.

Degraded Woodland- Land covered with tree species (more than 2m tall) which are Evergreen / Deciduous in nature with relatively decreased density of trees.

3.3.6 Littoral/Swamp/Mangroves

Mangroves- A shrub or tree that grows mainly in coastal saline or brackish water. Mangroves grow in an equatorial climate, typically along coastlines and tidal rivers

Swamp– These are wetlands dominated by woody plants. Swamps can be found in a variety of settings, including coastal areas, river deltas, and floodplains.

3.3.7 Grassland Land

These are the areas of natural grass along with other vegetation, predominantly grass-like plants (Monocots) and non-grass-like herbs (except Lantana species which are to be classified as scrub). It includes natural/semi-natural grass/ grazing lands of Alpine/Sub-Alpine or temperate or sub-tropical or tropical zones and deserted areas.

3.3.8 Shifting Cultivation

Shifting cultivation is a type of agriculture in which plots of woodland are cleared and cultivated temporarily, then abandoned while post-disturbance fallow vegetation is allowed to freely grow while the cultivator moves on to another plot. The period of cultivation is usually terminated when the soil shows signs of exhaustion. The period of time during which the field is cultivated is usually shorter than the period over which the land is allowed to regenerate by lying fallow.

Shifting cultivation is a common practice in tropical and subtropical regions, where it is often referred to as slash-and-burn agriculture. It is a traditional method of farming that has been practiced for centuries by indigenous peoples. Mostly situated in North-Eastern parts of India.

3.3.9 Wastelands

Wastelands are degraded lands which can be brought under vegetative cover with reasonable effort and which is currently underutilized and land which is deteriorating for lack of appropriate water and soil management or on account of natural causes. It includes rocky areas, scrub lands, mining dumps, gullied lands, sand dunes etc. (NRSC 2019).

3.3.10 Rann

Rann is a large area of salt marsh located in the western India between the Gulf of Kutch and the Indus River delta. Rann experience high ambient temperature at one point of time while it gets flooded by both the tidal water ingression and freshwater poured by the seasonal rivers during the monsoon season.

3.3.11 Water Bodies

This category comprises areas with surface water, either impounded in the form of reservoirs, lakes, ponds, aquaculture lands etc., or flowing in the form of rivers, canals, streams etc.

Maximum spread – Water Bodies at their maximum capacity i.e. the maximum extent of surface water immediate after monsoon of the particular year.

Minimum spread – This represents the least water spread in a water body like lakes, tanks, reservoirs, rivers, etc..

3.3.12 Snow Covered / Glacial areas

Due to a confluence of environmental variables, certain lands maintain a permanent layer of snow or ice that prevents them from melting during the summer. As a result, they continue to exist as rather stable landscape features. Adjacent lands most commonly will be of Water, Wetland, Barren Land, or Tundra, with their common boundaries being distinguished from the satellite data acquired in summer.

4. Maps & Statistics

Extant Section illustrates the outputs from the long term analysis of land use land cover datasets in terms of National level maps and related statistical quantities. Outputs are arranged as Annual LULC map for 18 classes followed by kharif and rabi season maps for entire country. It is followed by histograms of state-wise land cover statistics arranged in descending order of TGA of states. These TGA have been categorized in to four levels viz., > 130 L ha, 43-130 L ha, 1-43 L ha and < 1 L ha, to facilitate inter-comparison of land cover distribution.

Patterns of land cover as well as seasonal crop manifestation and trends of cover category quantities across and within states provide distinct insights of each of stakeholder groups employing this information for planning, research, analysis, modeling as well as outreach as analytical or reference data.

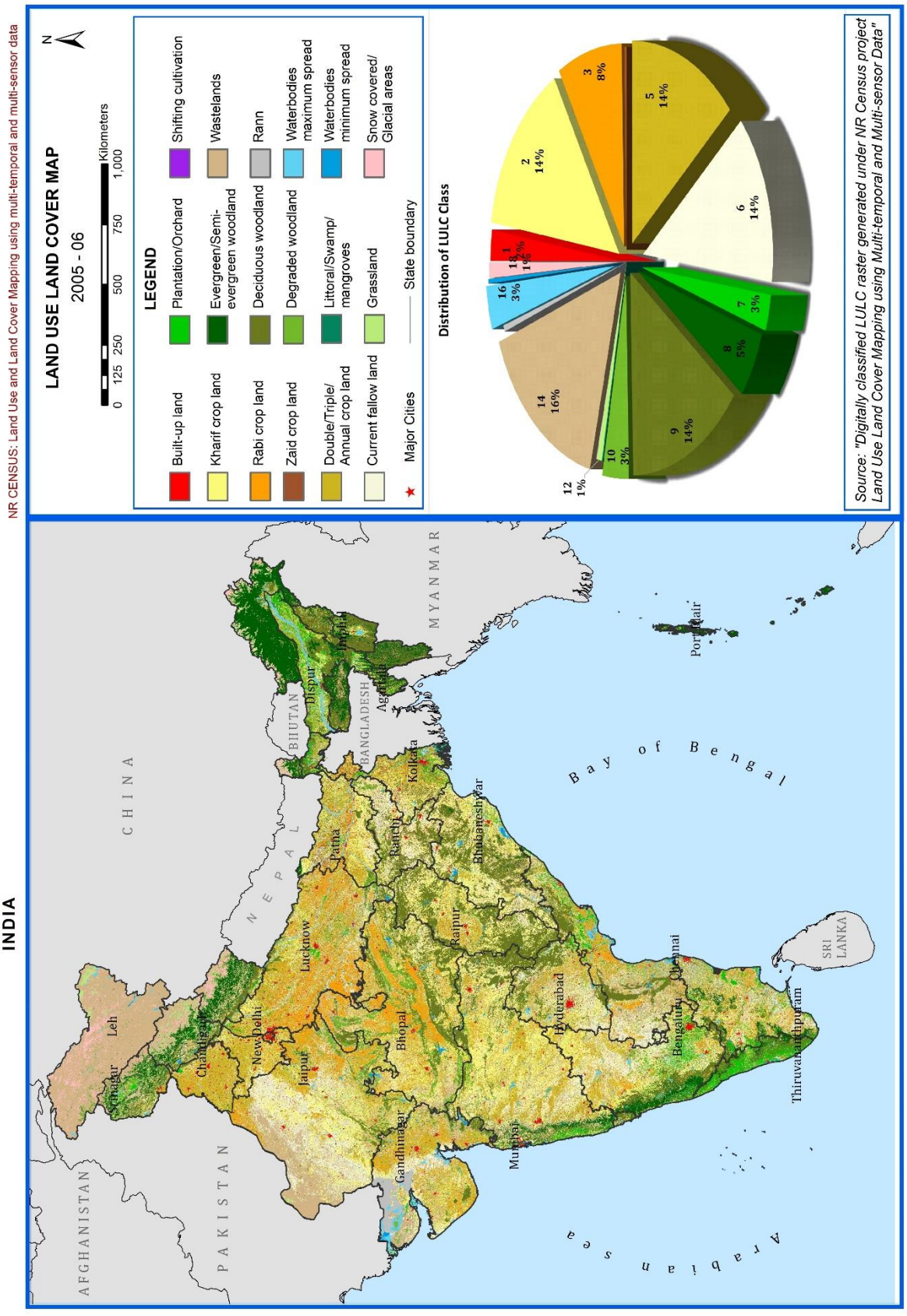

Figure 3- LULC map 2005-06

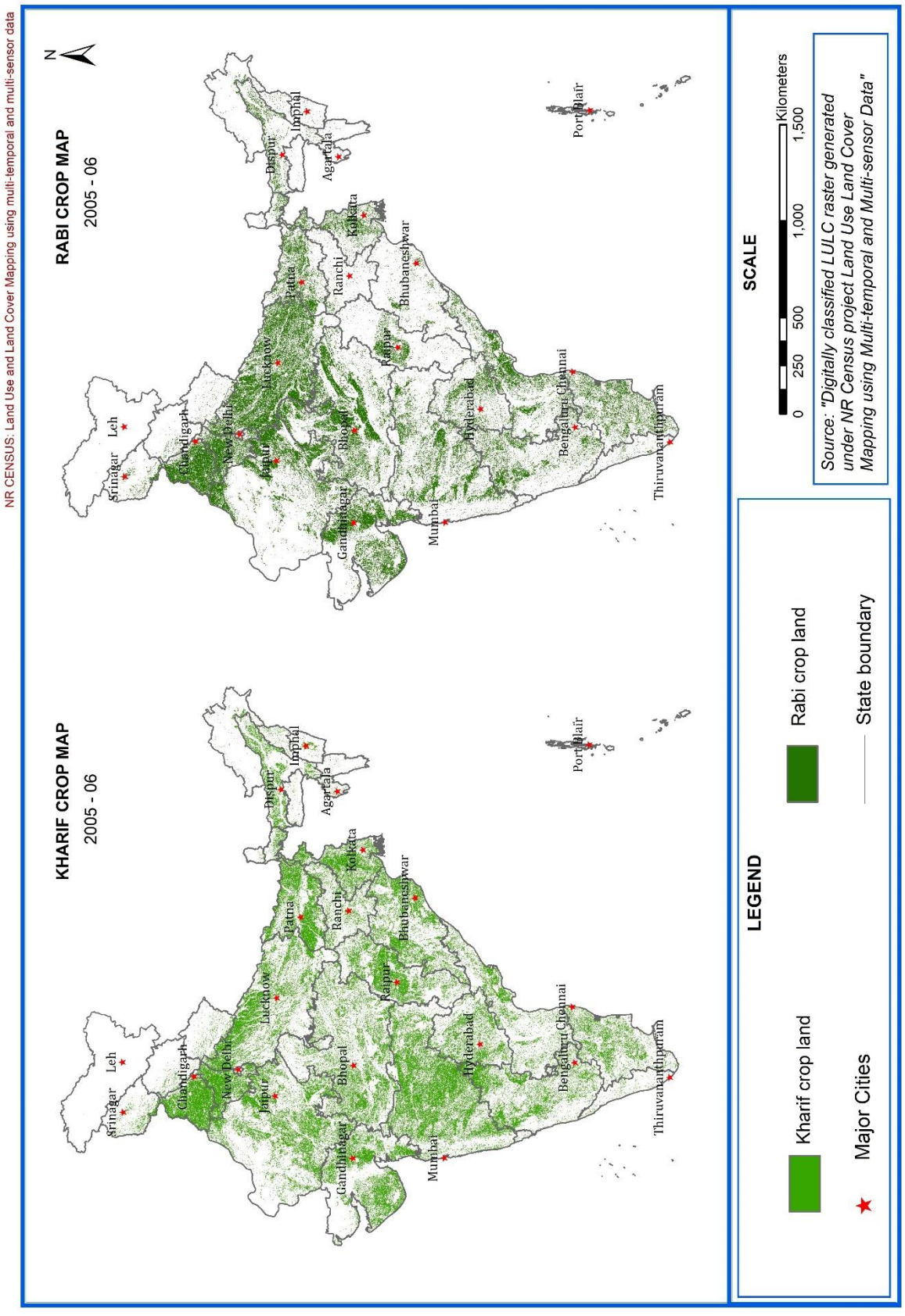

Figure 4-Crop map 2005-06

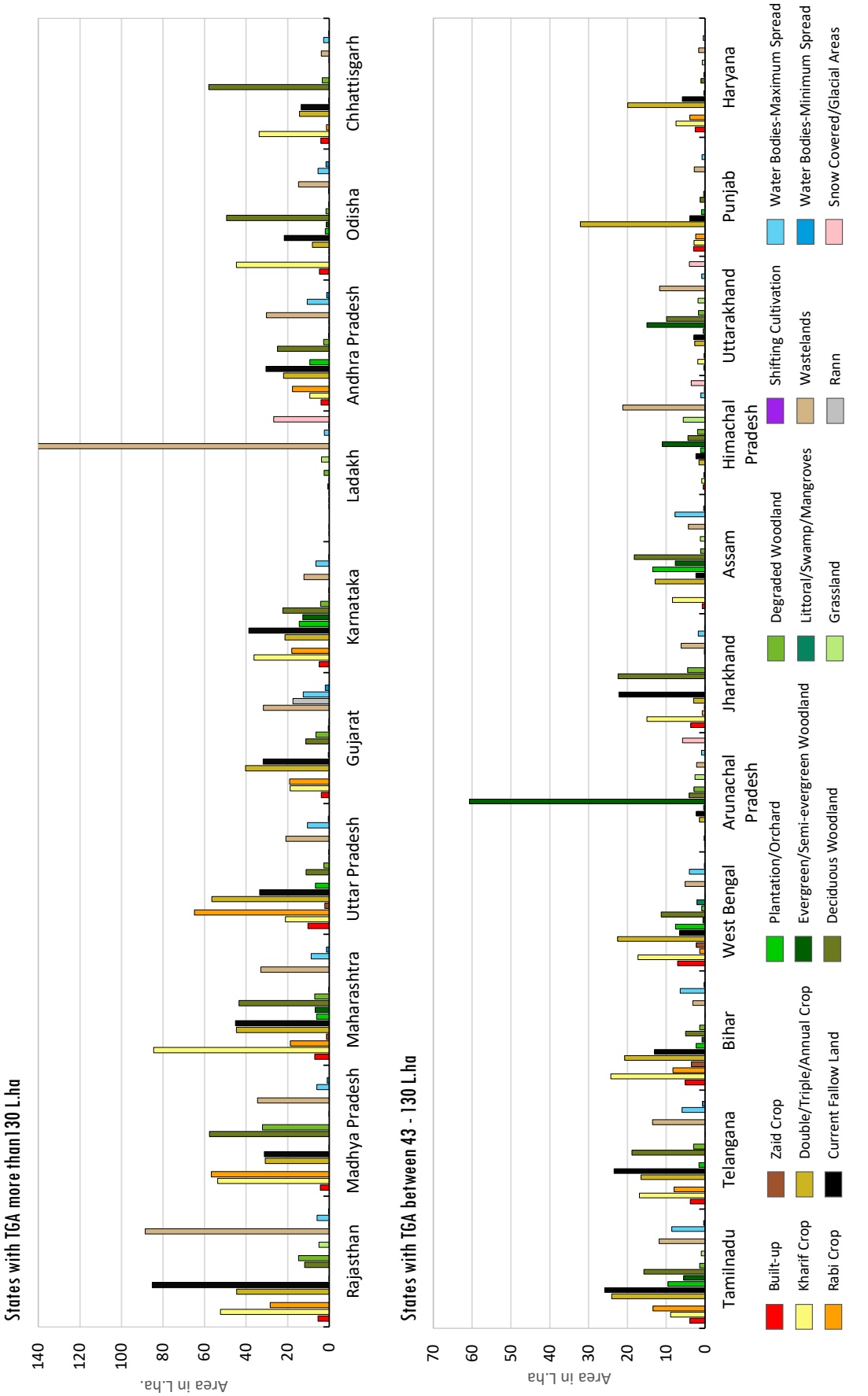

Chart 1- Distribution of Class-wise Land Use & Land Cover Extents Across Indian States with TGA greater than 43 L.ha. (2005-2006)

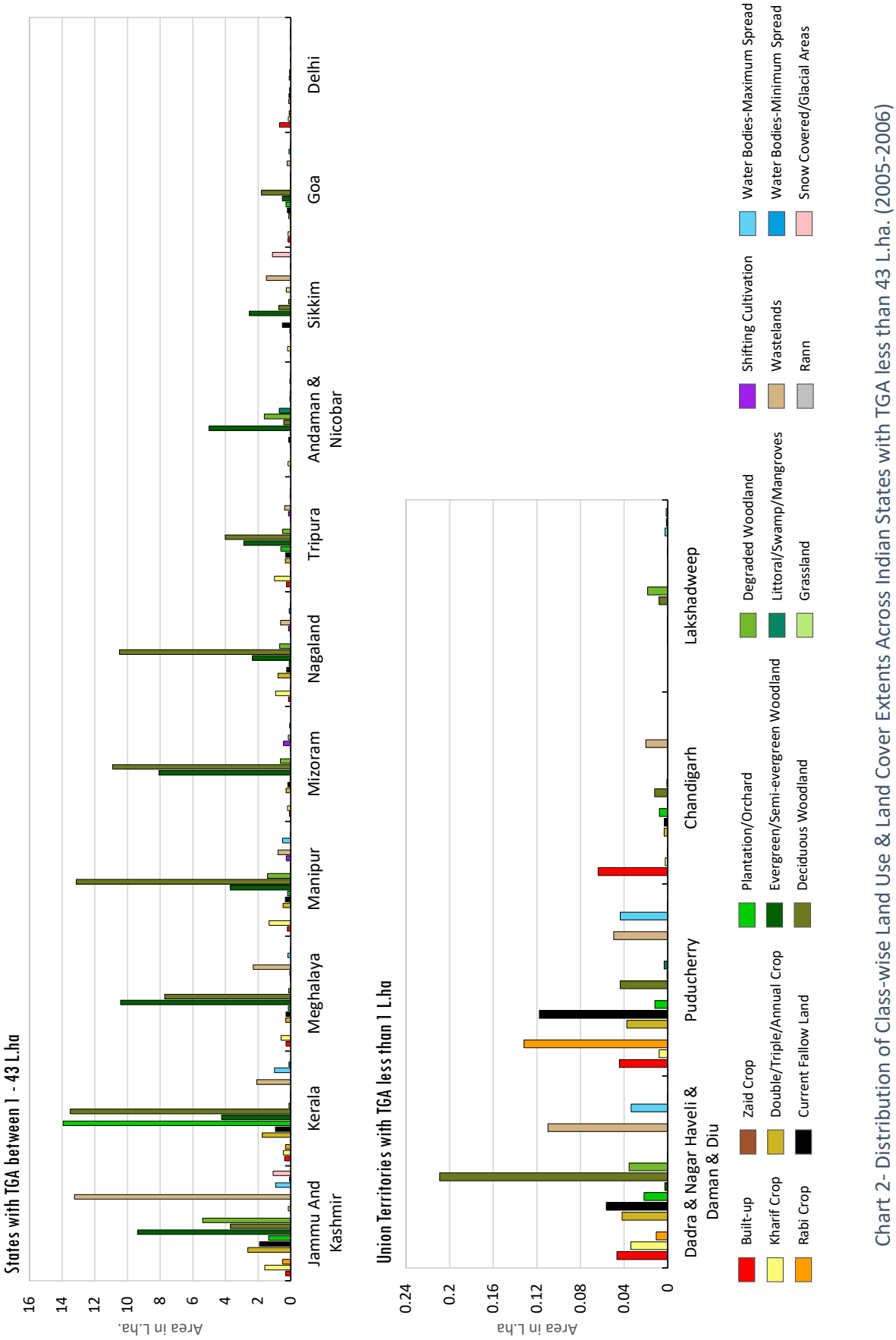

Chart 2- Distribution of Class-wise Land Use & Land Cover Extents Across Indian States with TGA less than 43 L.ha. (2005-2006)

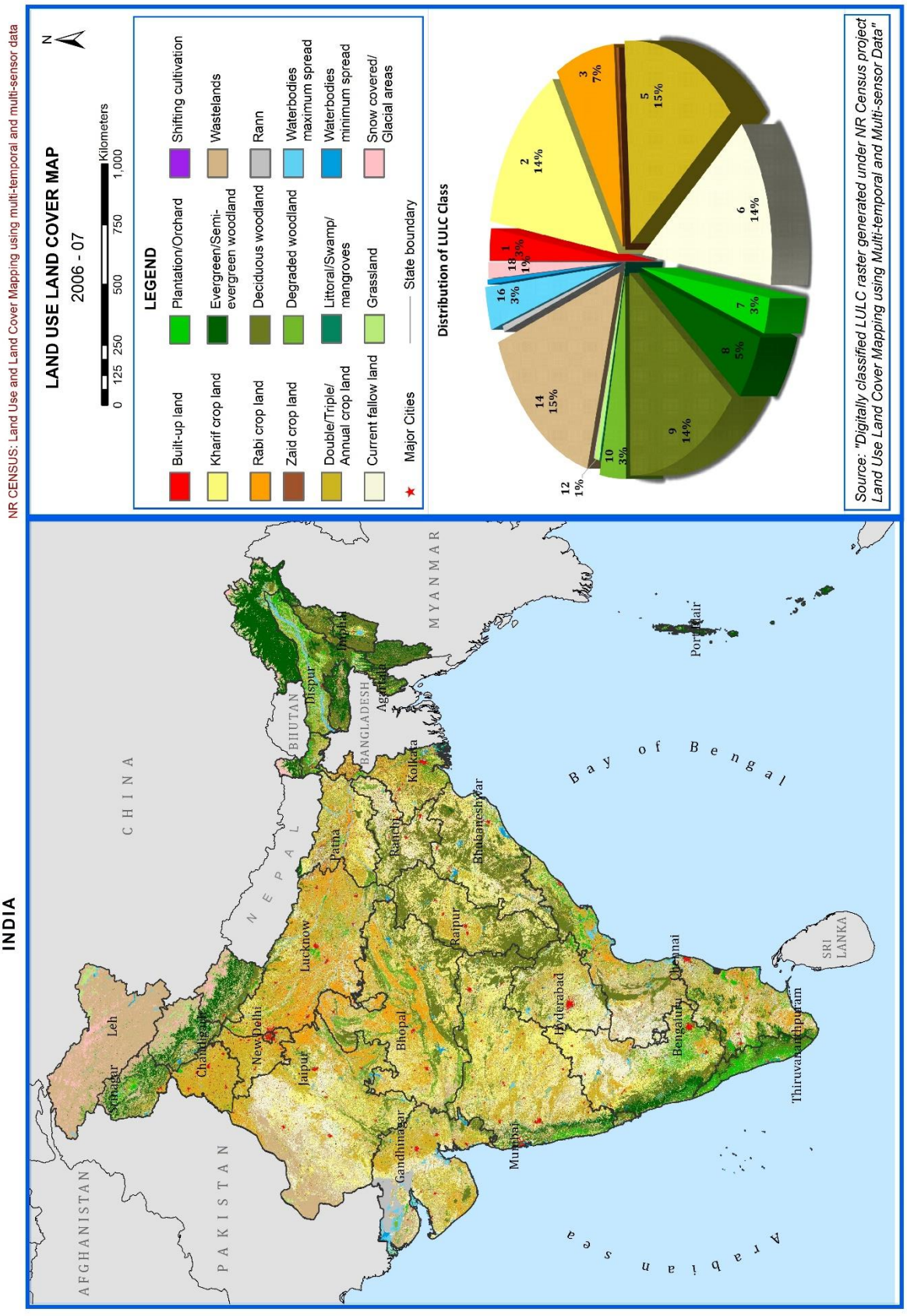

Figure 5- LULC map 2006-07

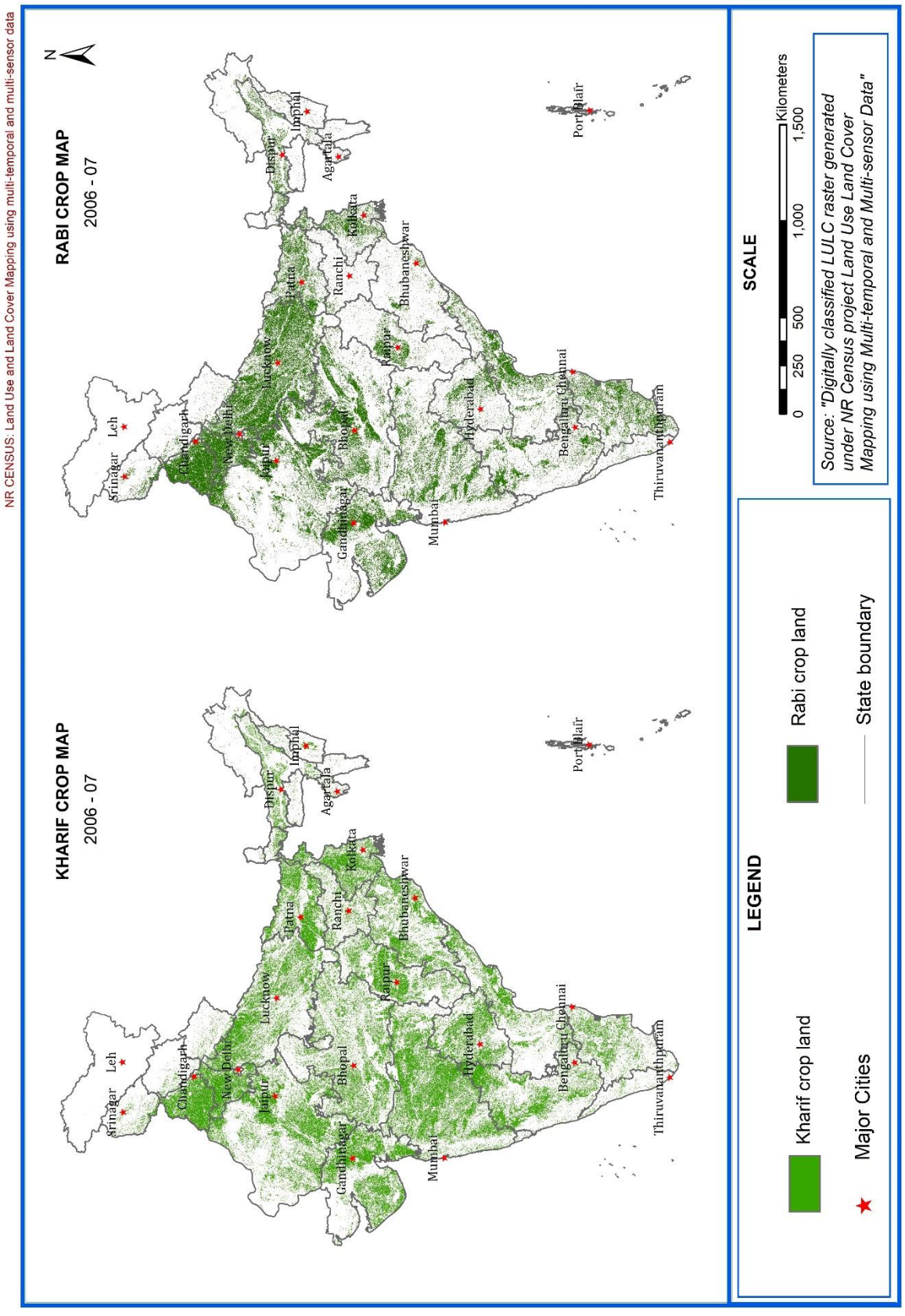

Figure 6- Crop map 2006-07

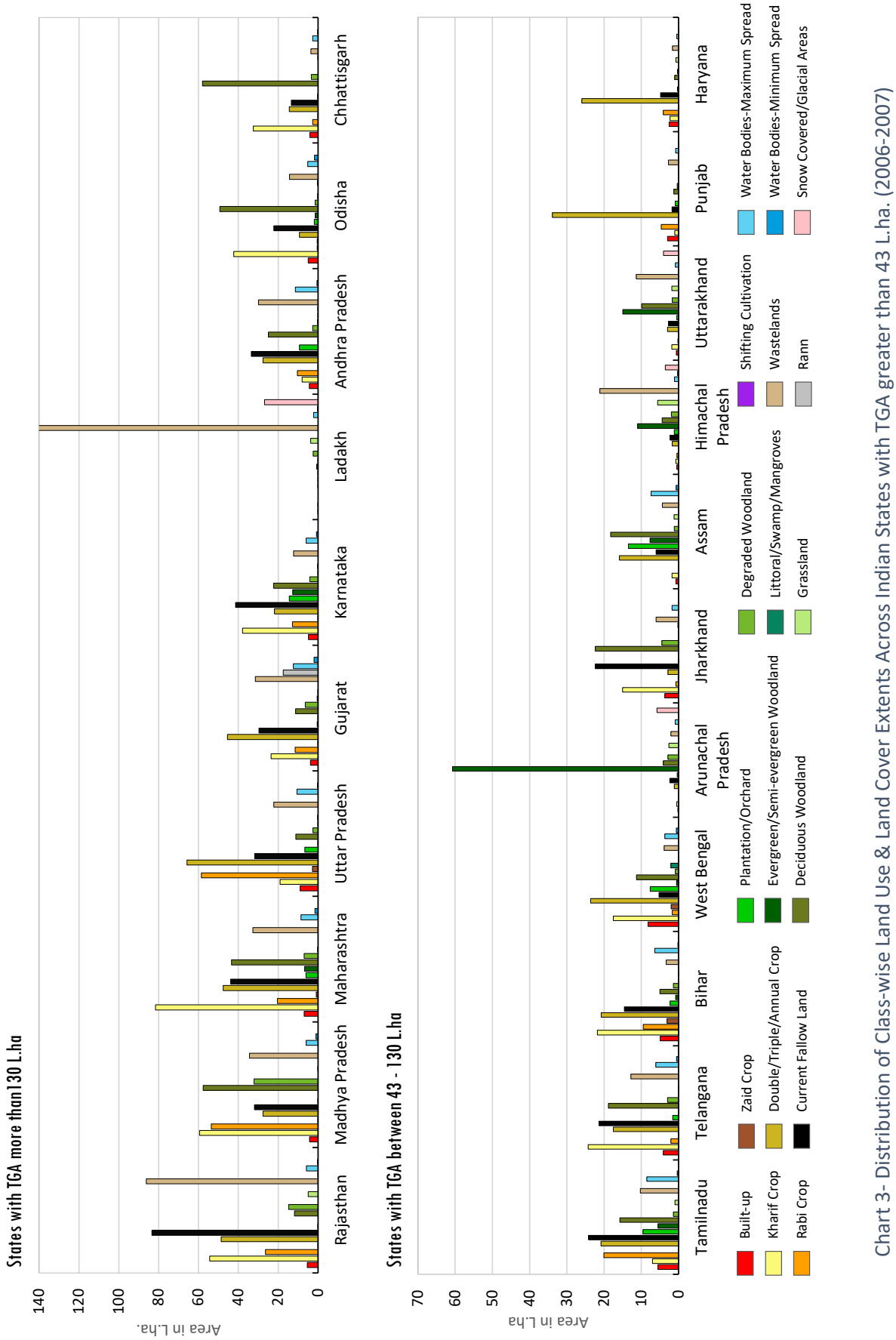

Chart 3- Distribution of Class-wise Land Use & Land Cover Extents Across Indian States with TGA greater than 43 L.ha. (2006-2007)

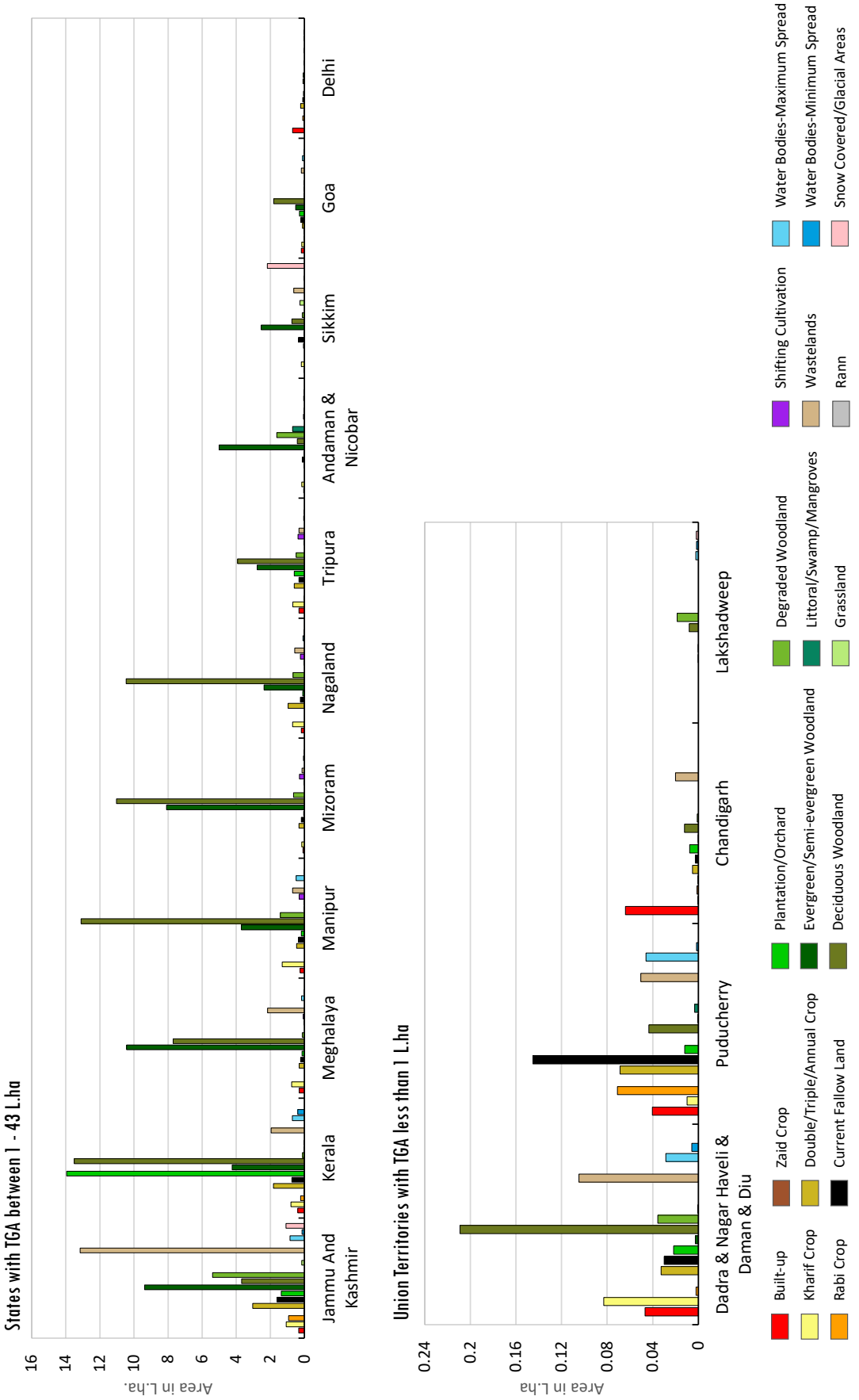

Chart 4- Distribution of Class-wise Land Use & Land Cover Extents Across Indian States with TGA less than 43 L.ha. (2006-2007)

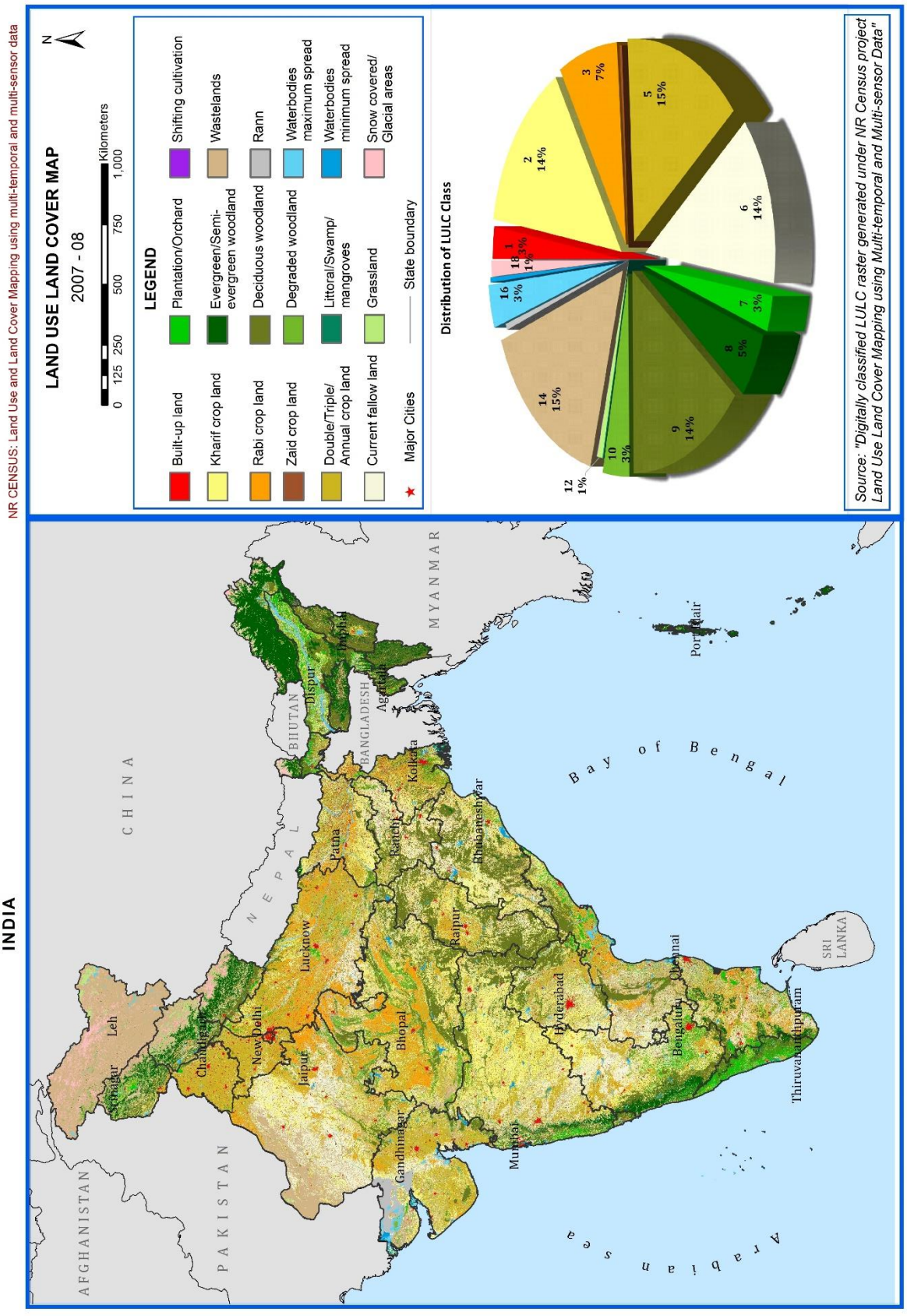

Figure 7- LULC map 2007-08

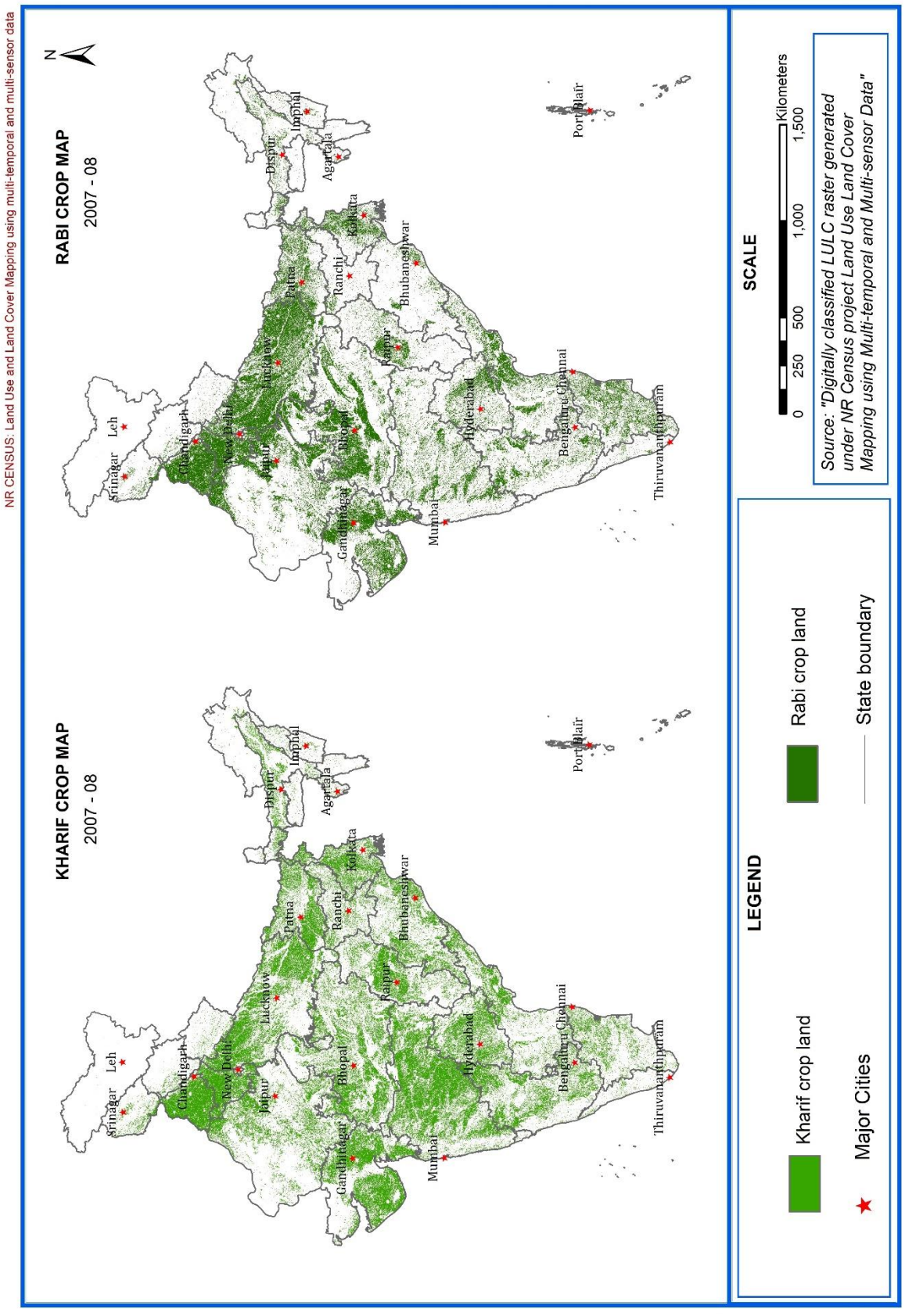

Figure 8- Crop map 2007-08

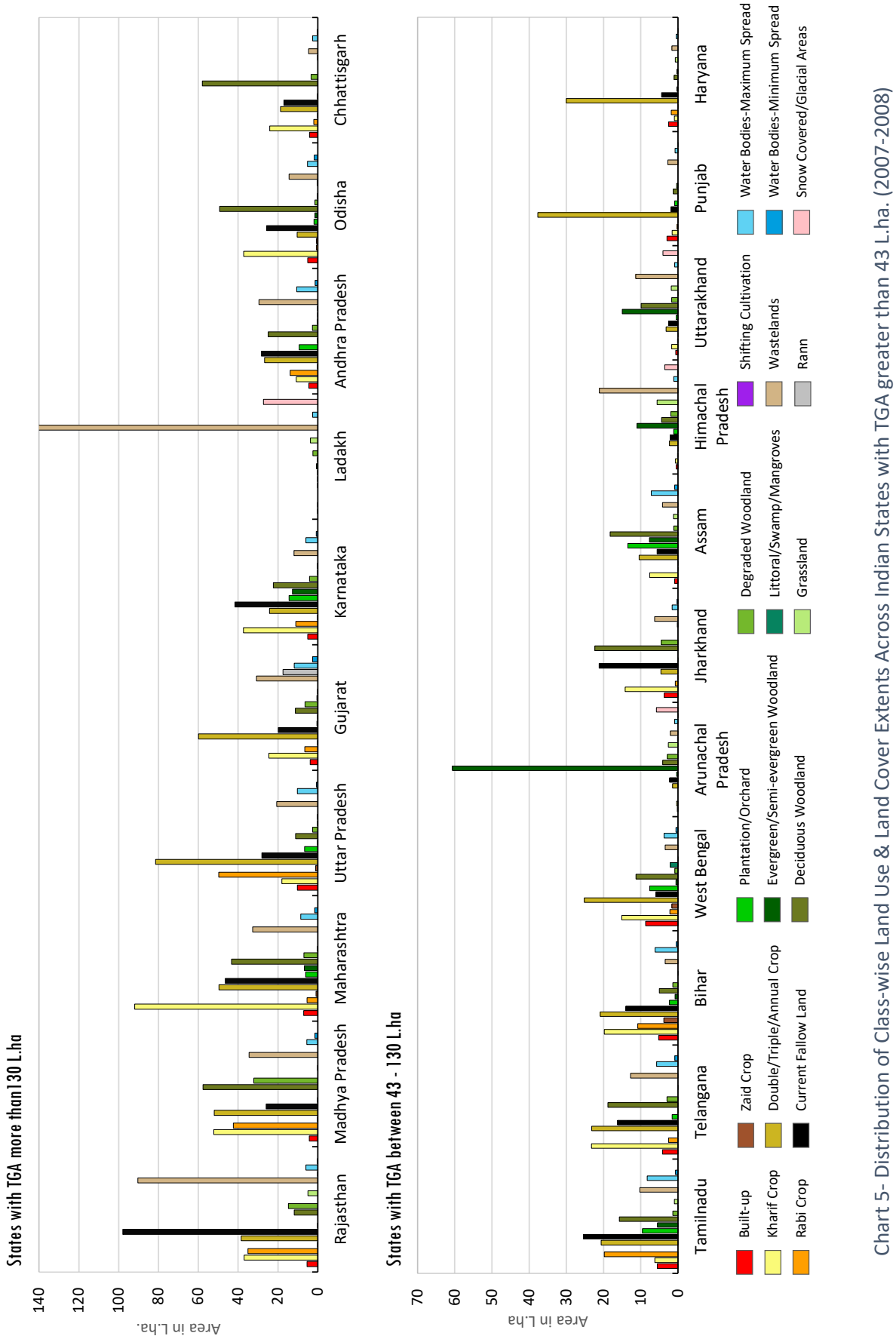

Chart 5- Distribution of Class-wise Land Use & Land Cover Extents Across Indian States with TGA greater than 43 L.ha. (2007-2008)

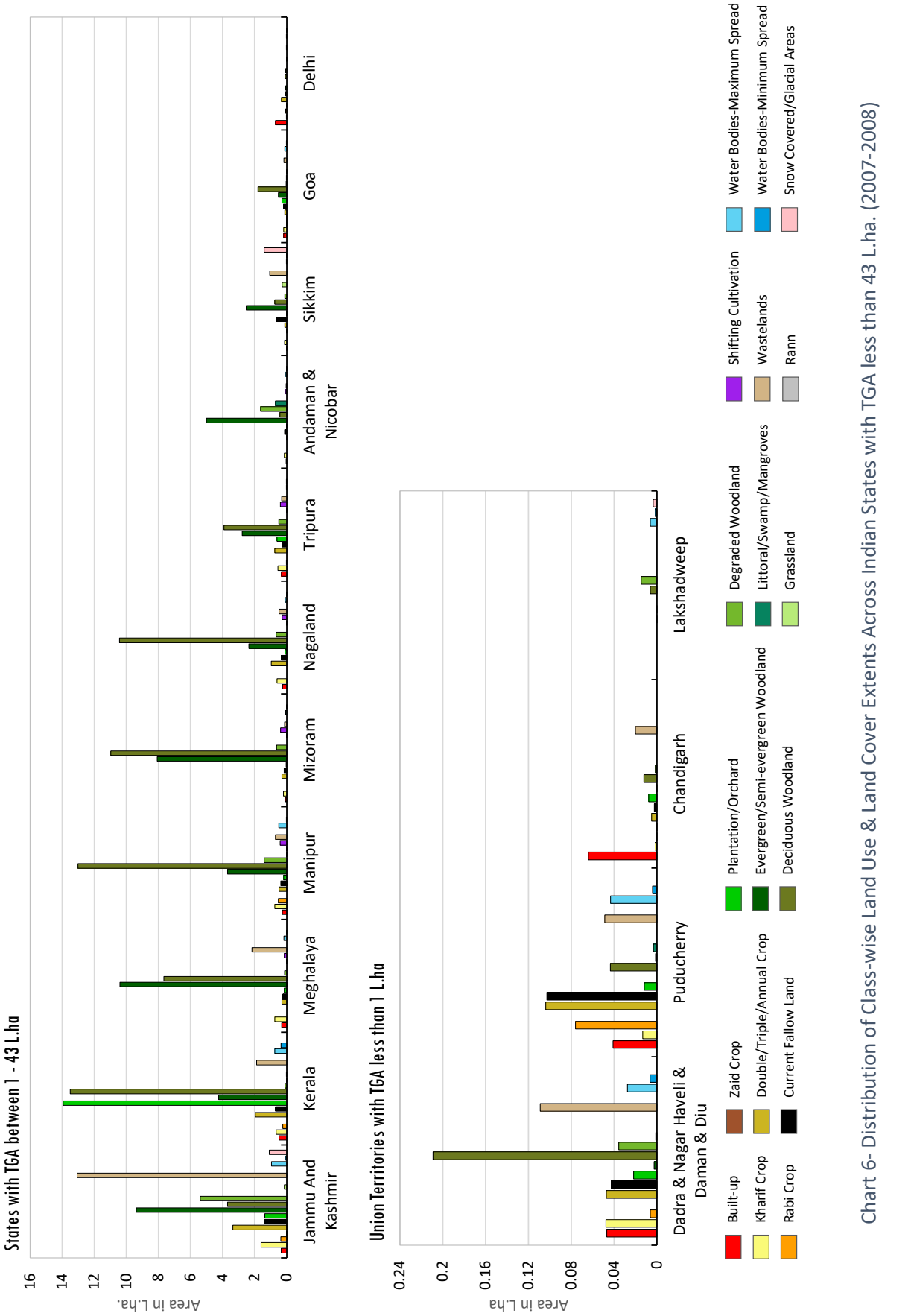

Chart 6- Distribution of Class-wise Land Use & Land Cover Extents Across Indian States with TGA less than 43 L.ha. (2007-2008)

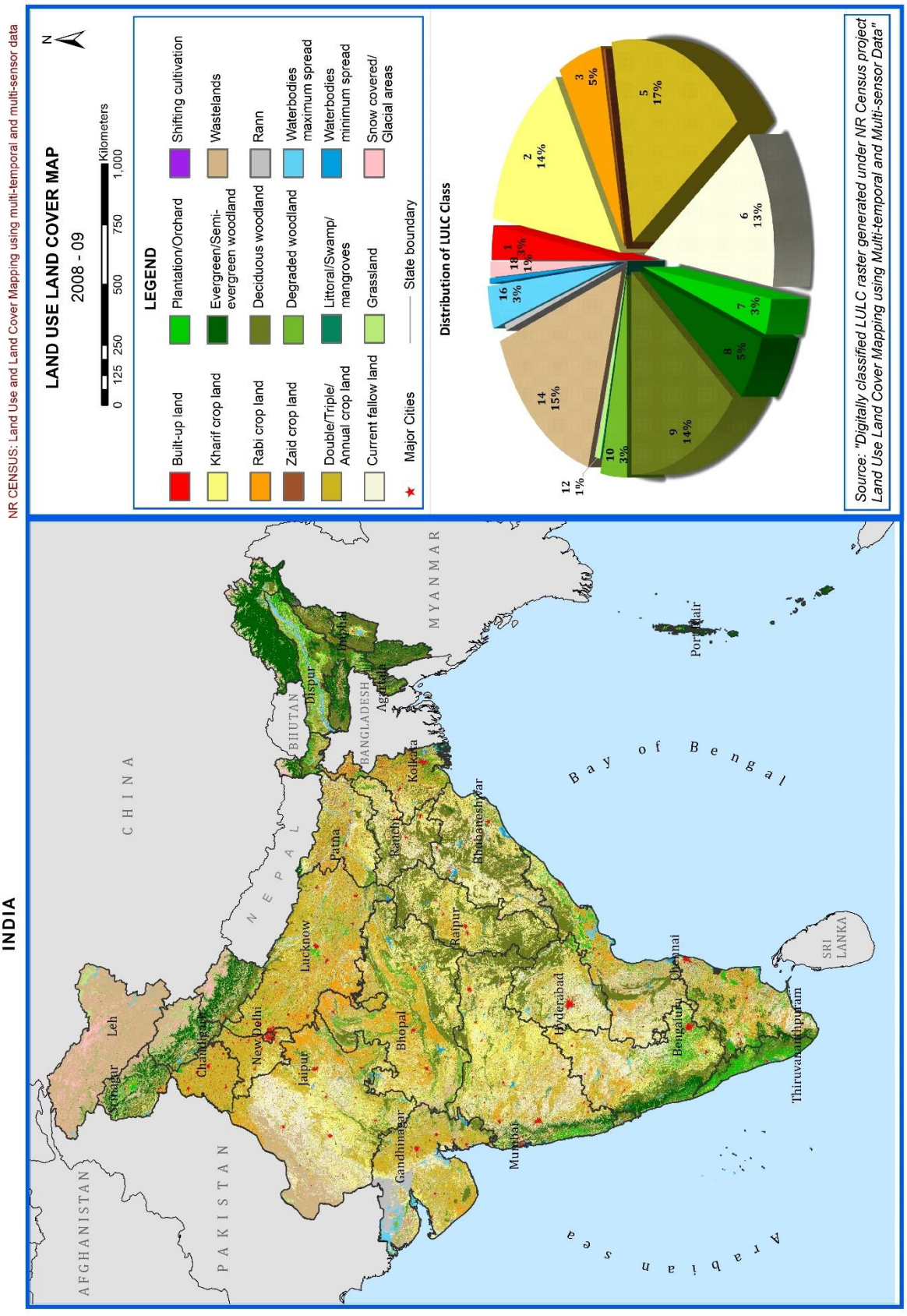

Figure 9- LULC map 2008-09

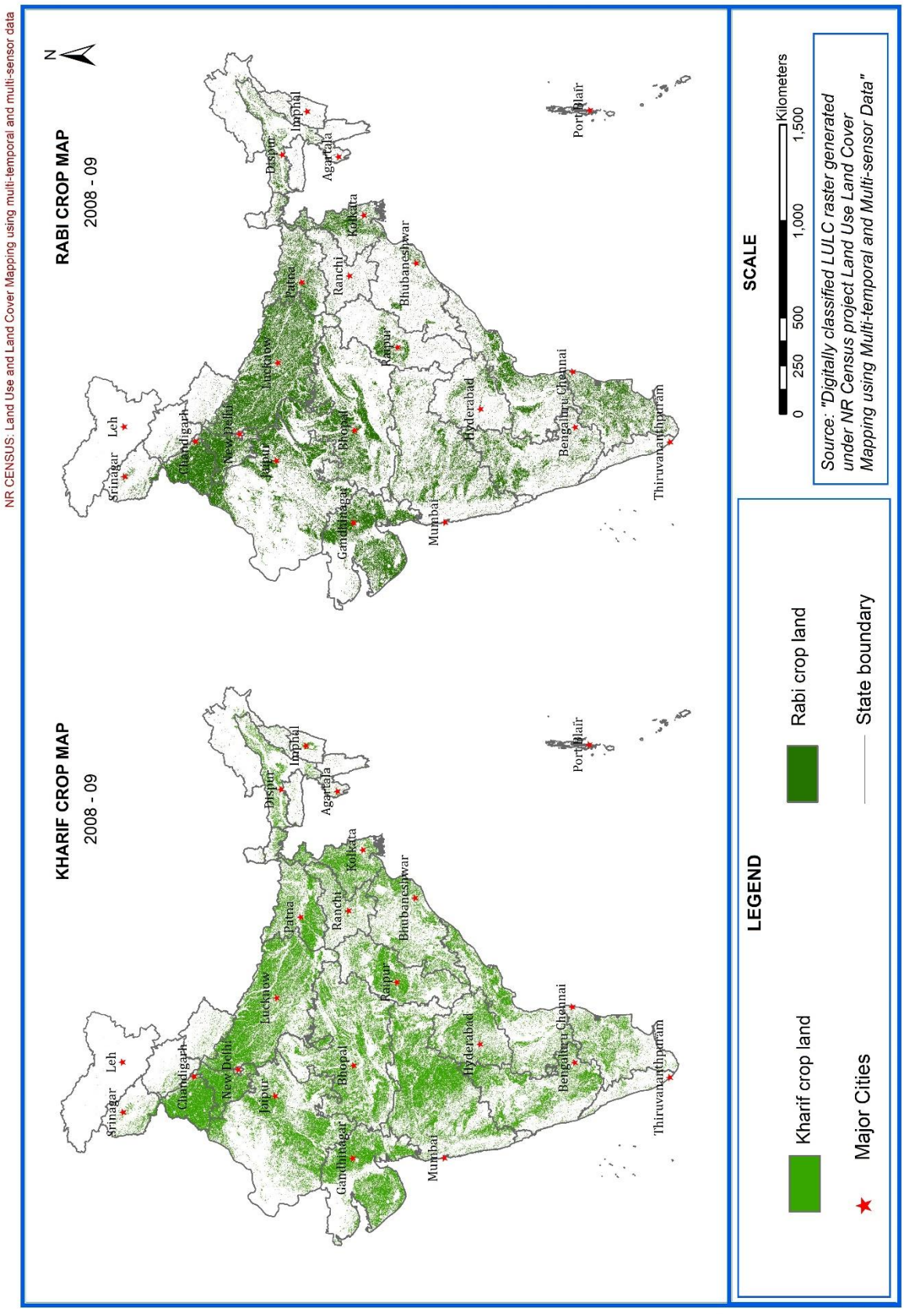

Figure 10- Crop map 2008-09

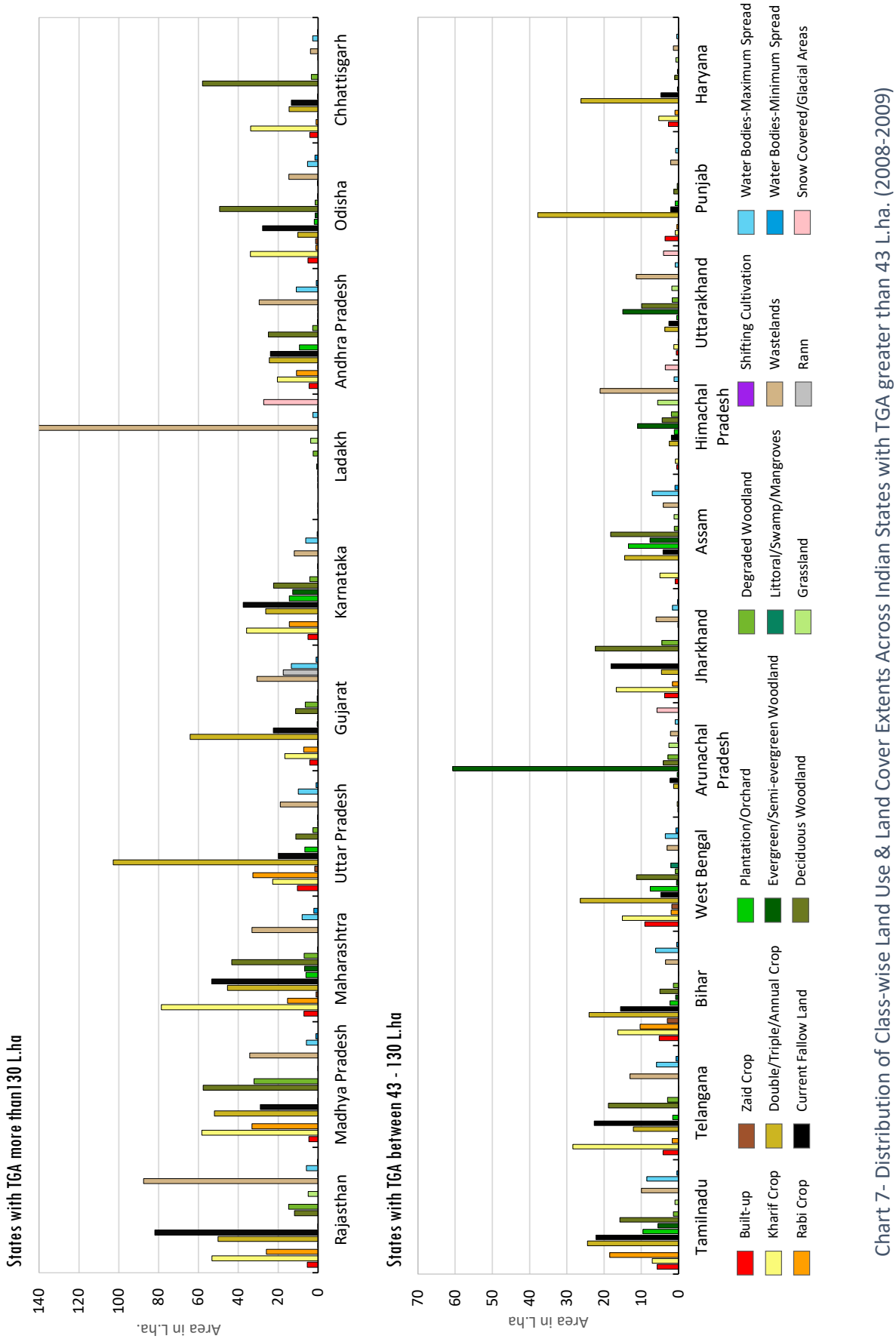

Chart 7- Distribution of Class-wise Land Use & Land Cover Extents Across Indian States with TGA greater than 43 L.ha. (2008-2009)

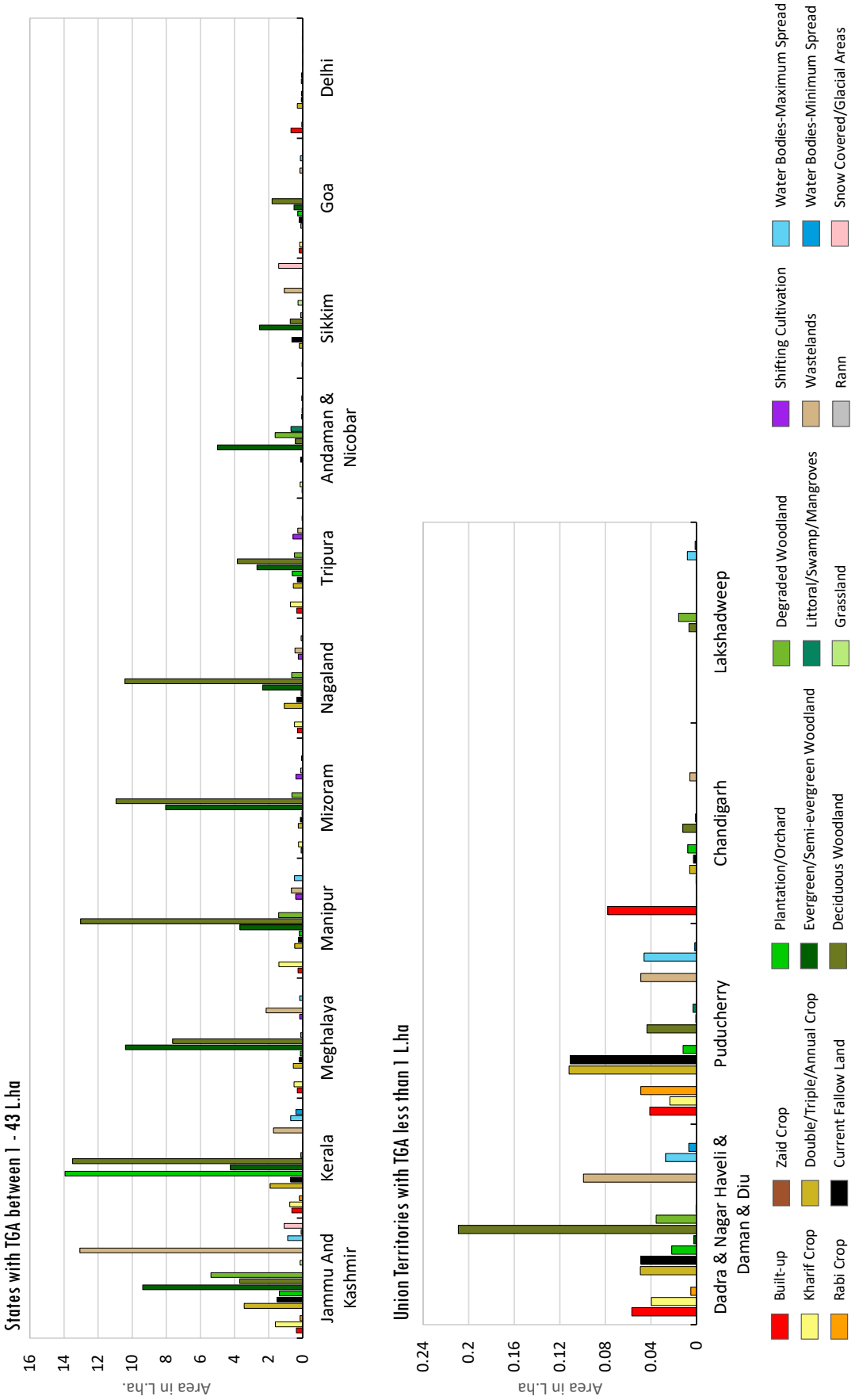

Chart 8- Distribution of Class-wise Land Use & Land Cover Extents Across Indian States with TGA less than 43 L.ha. (2008-2009)

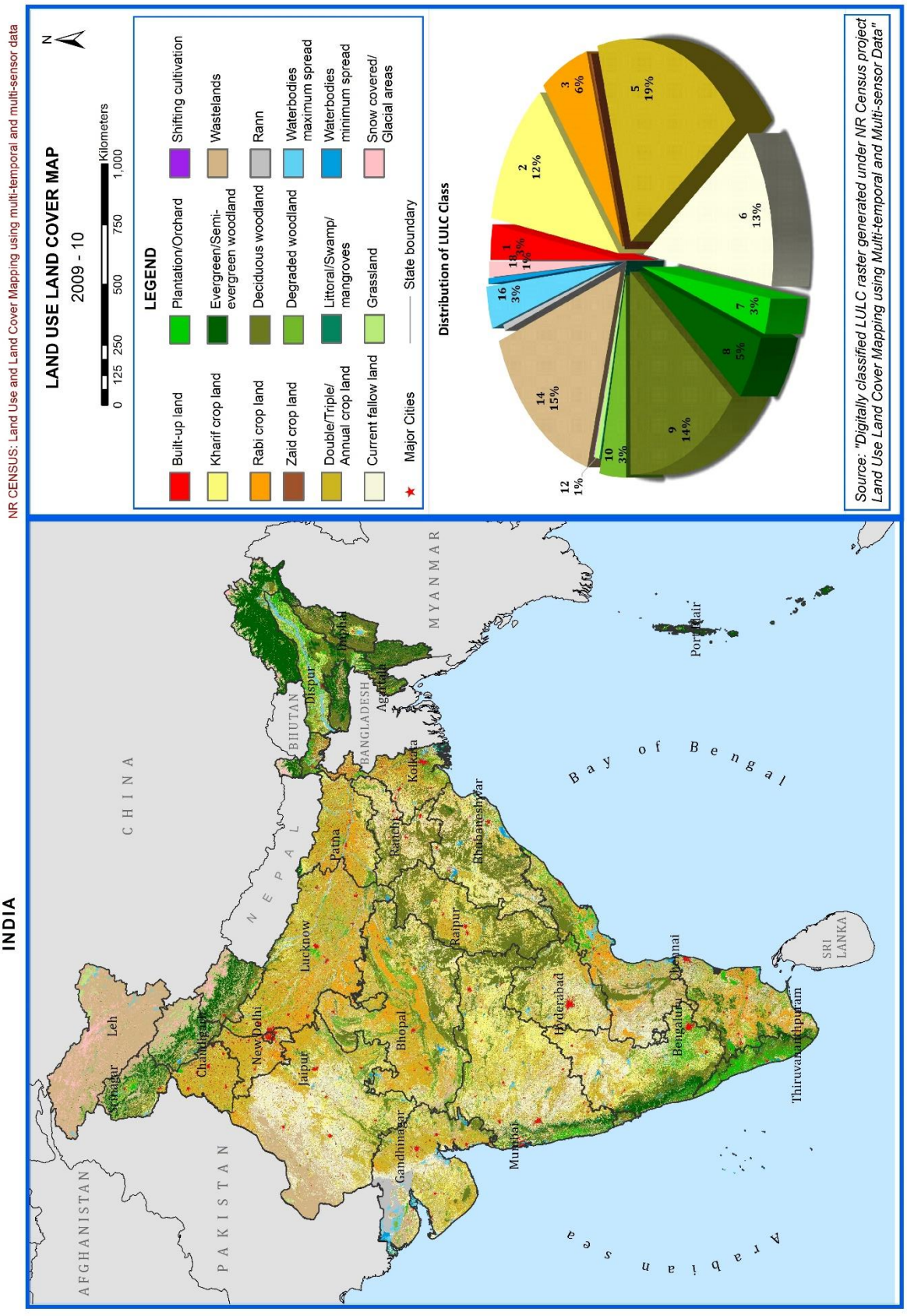

Figure 11- LULC map 2009-10

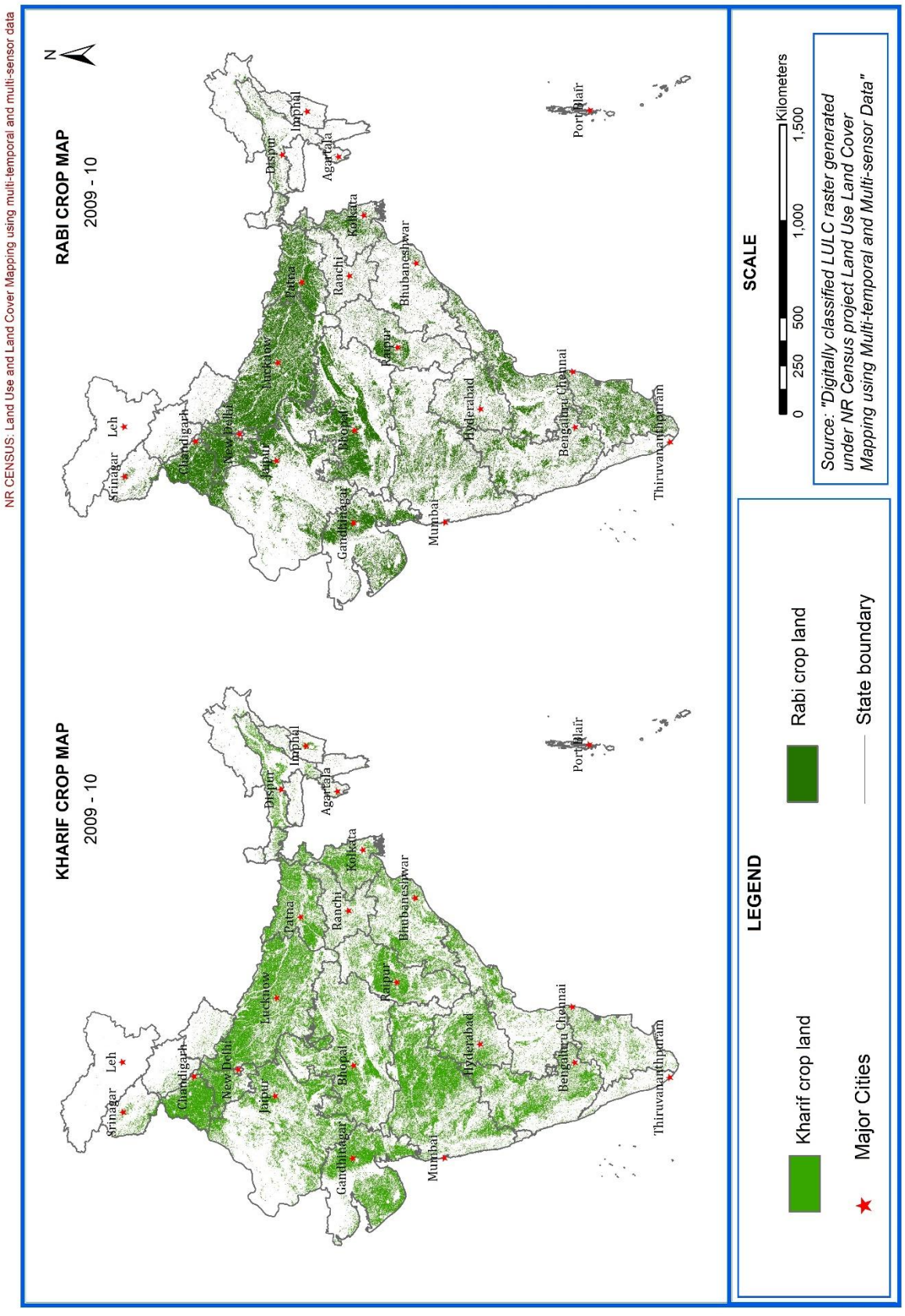

Figure 12- Crop map 2009-10

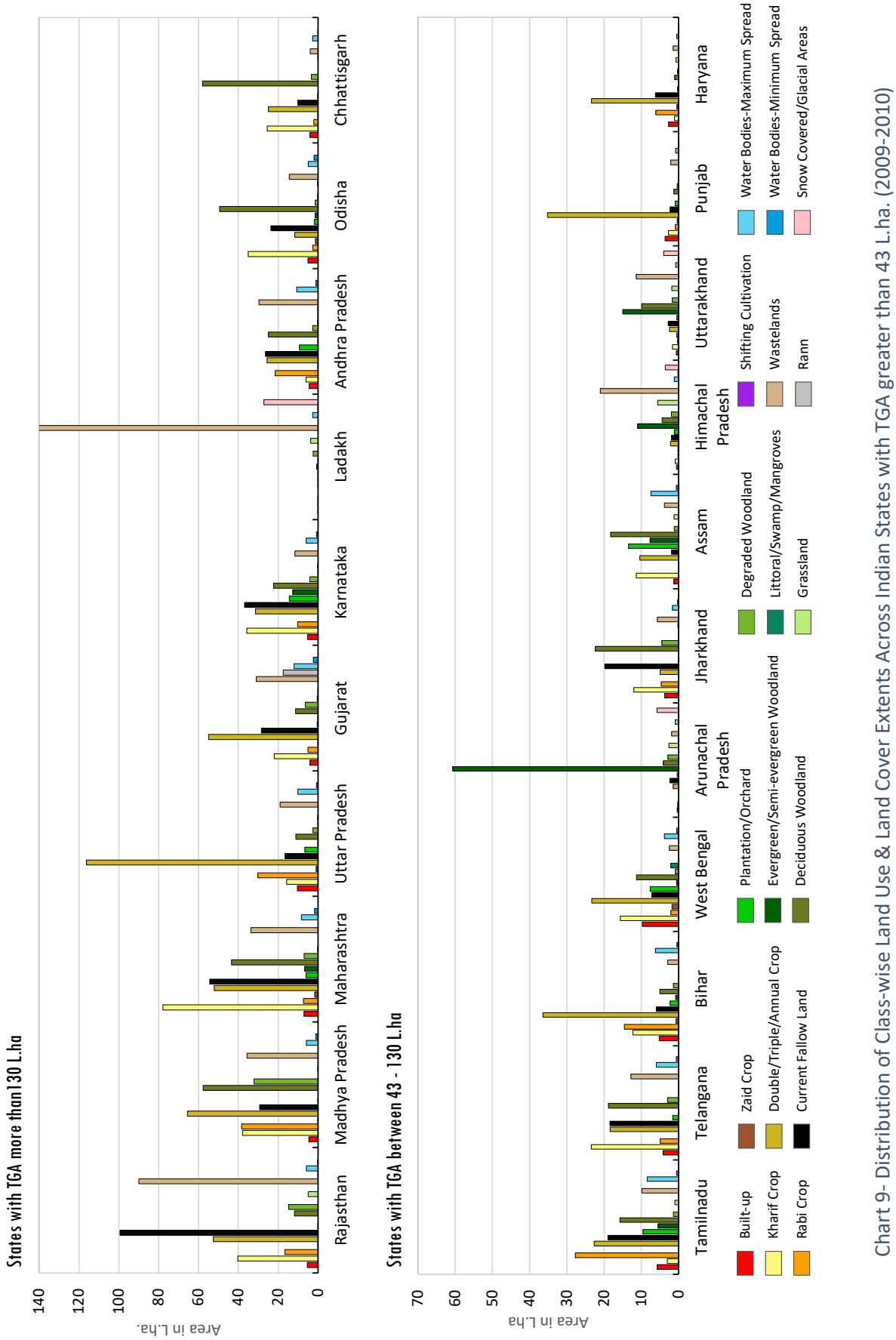

Chart 9- Distribution of Class-wise Land Use & Land Cover Extents Across Indian States with TGA greater than 43 L.ha. (2009-2010)

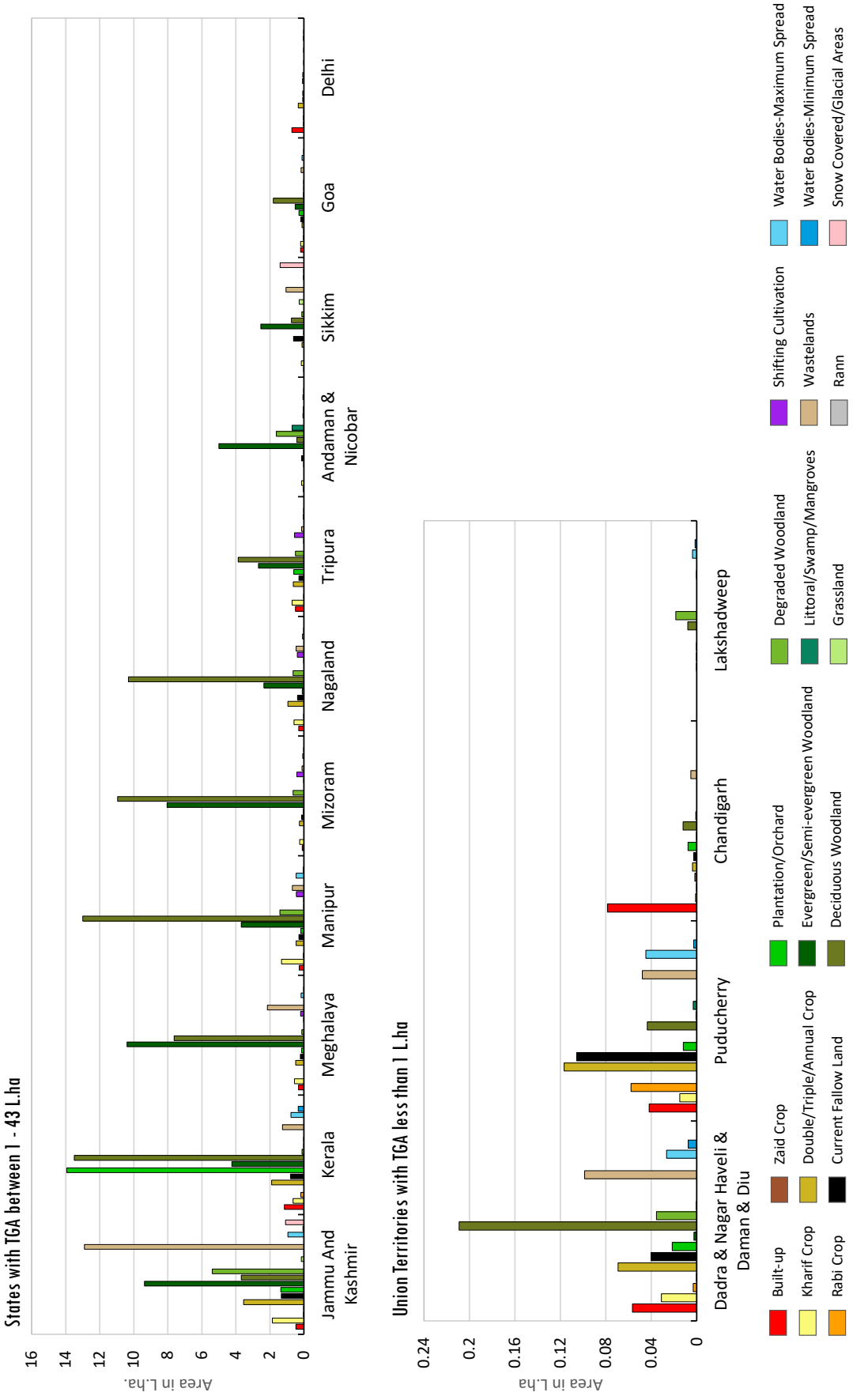

Chart 10- Distribution of Class-wise Land Use & Land Cover Extents Across Indian States with TGA less than 43 L.ha. (2009-2010)

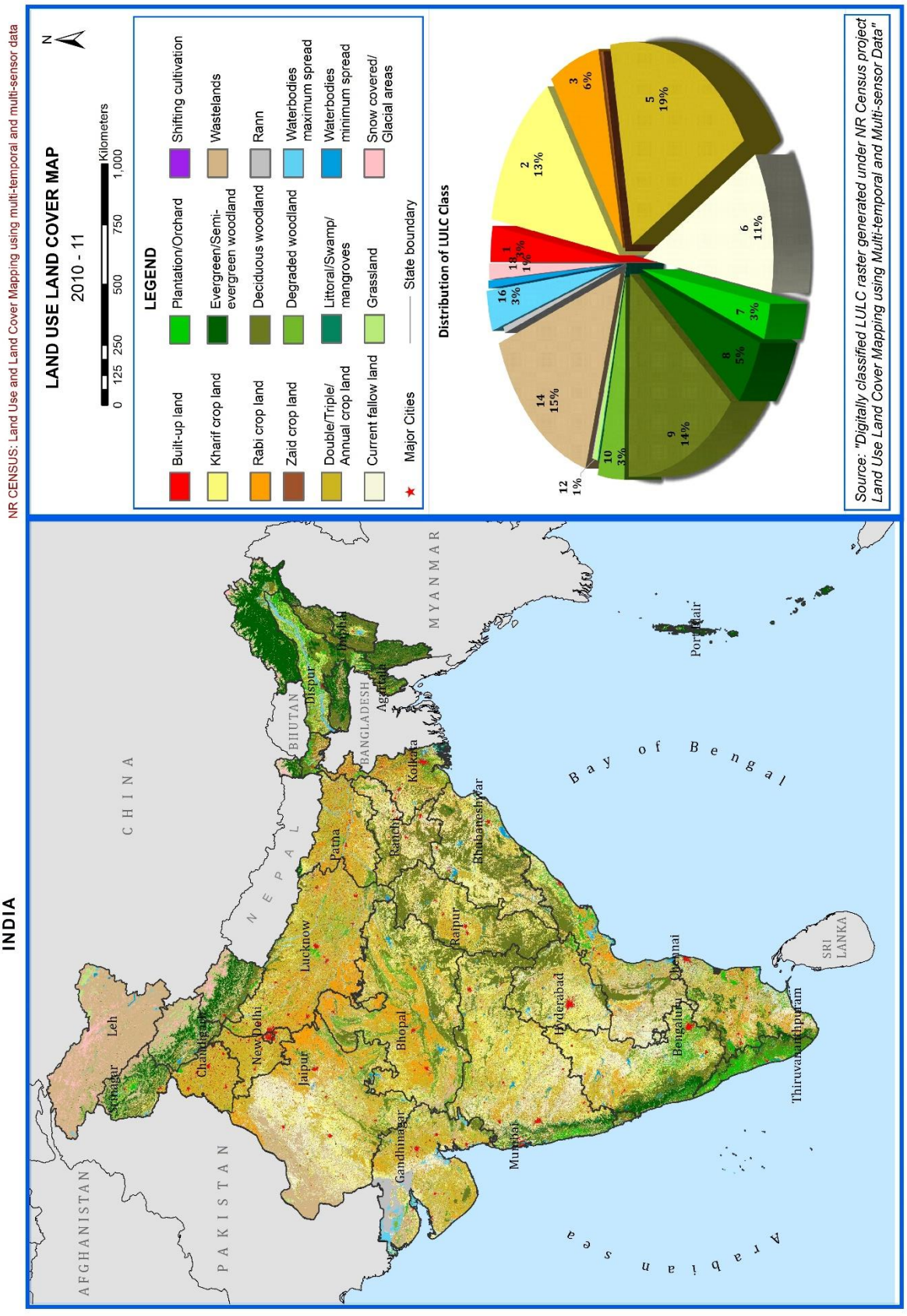

Figure 13- LULC map 2010-11

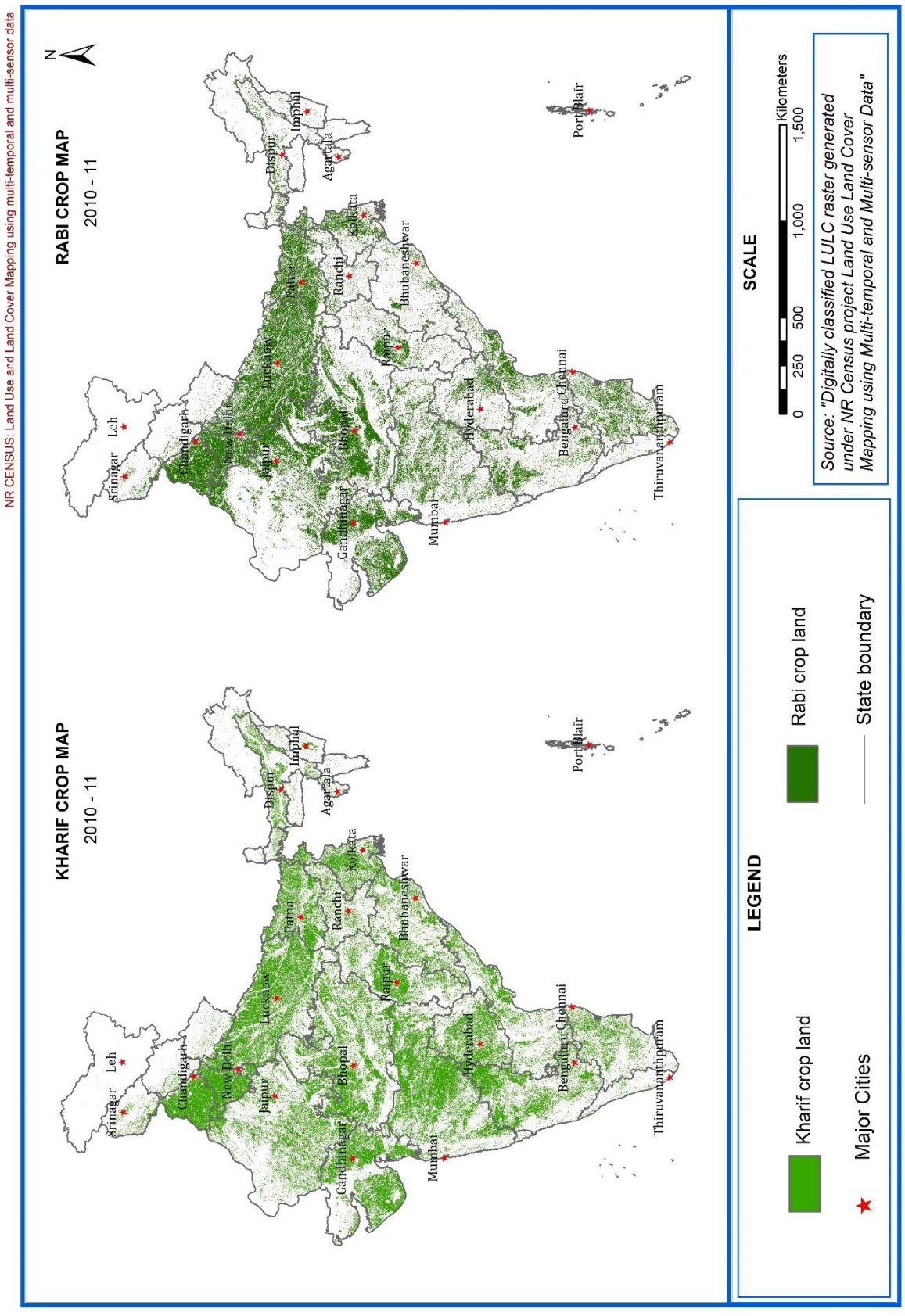

Figure 14- Crop map 2010-11

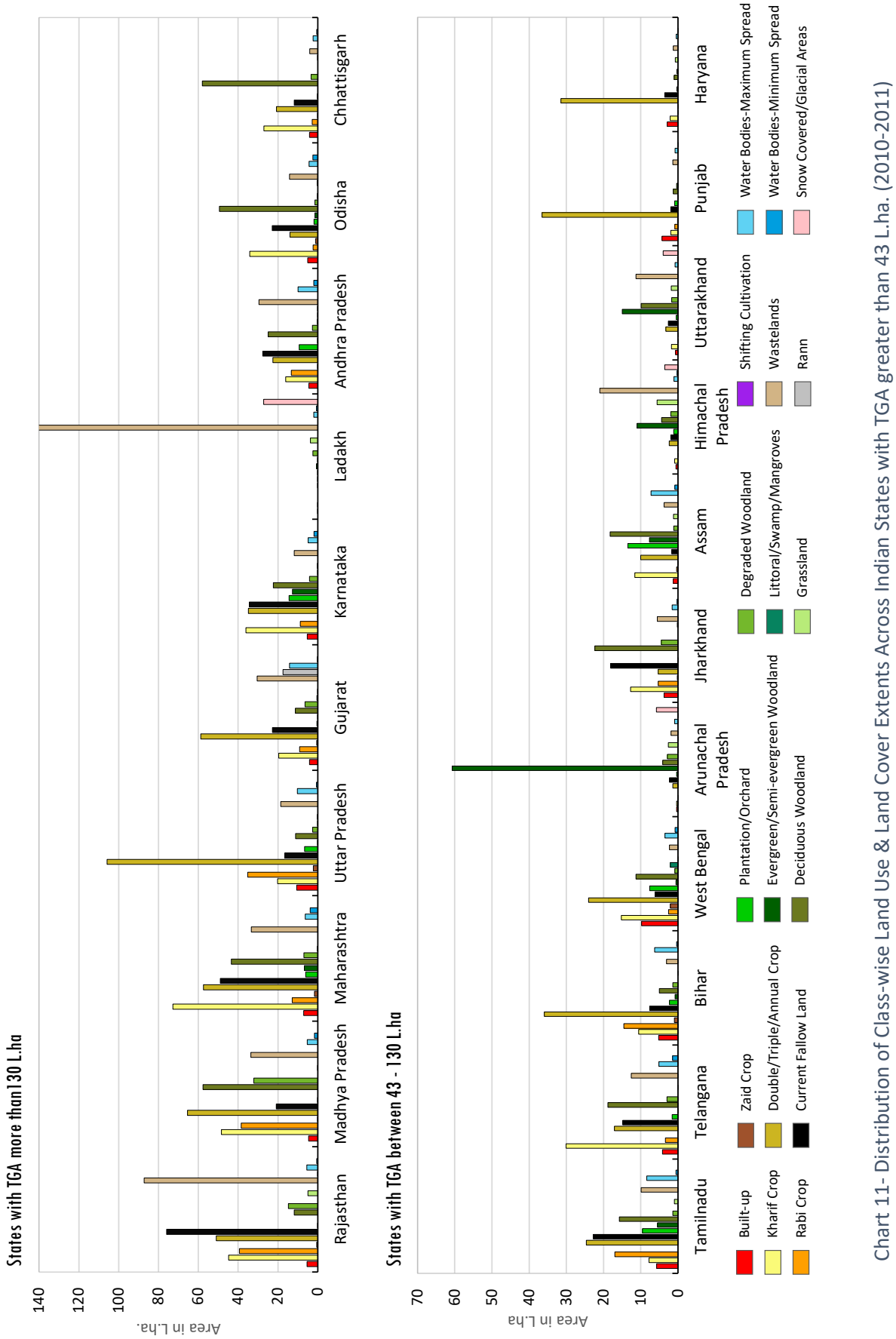

Chart 11- Distribution of Class-wise Land Use & Land Cover Extents Across Indian States with TGA greater than 43 L.ha. (2010-2011)

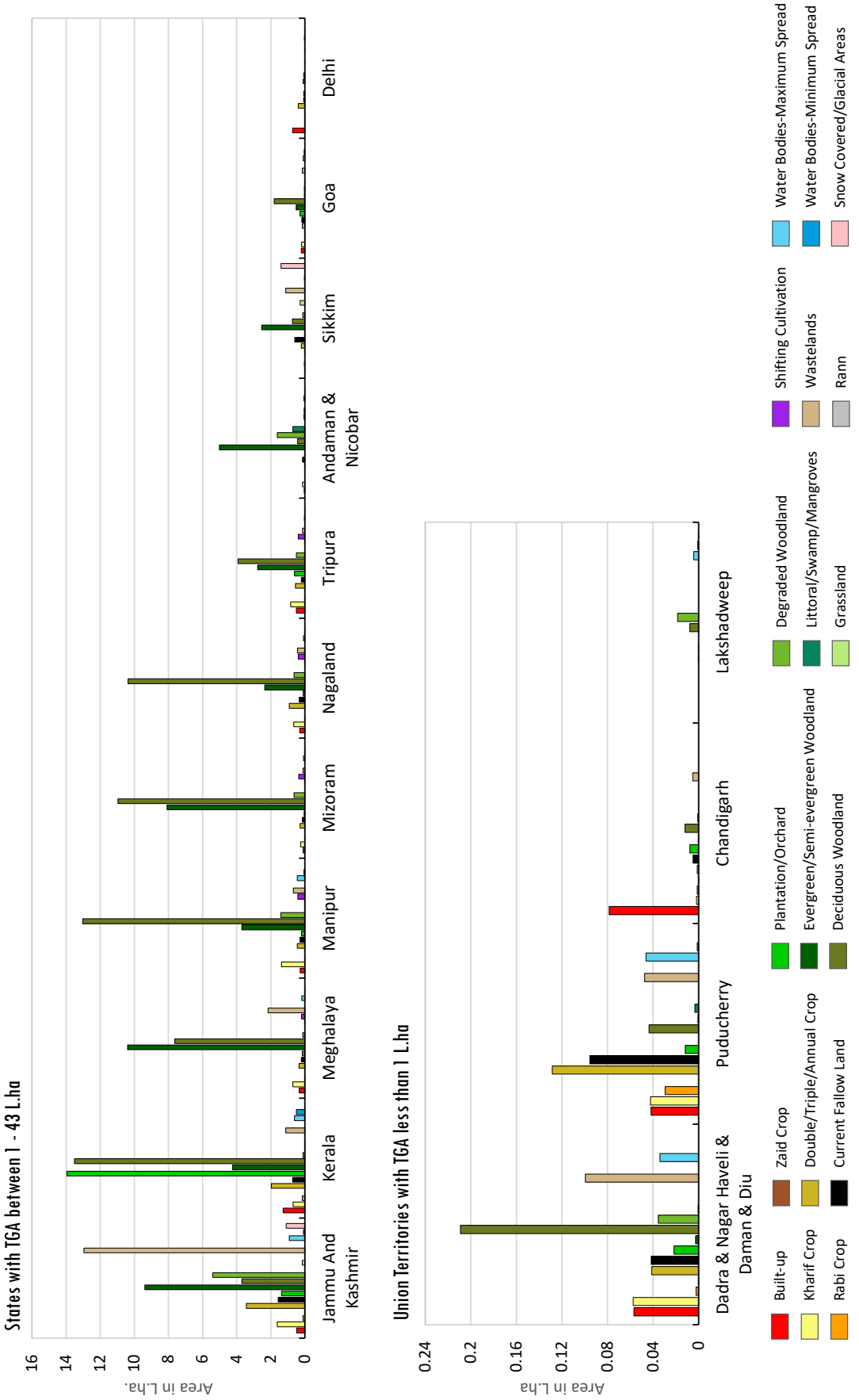

Chart 12- Distribution of Class-wise Land Use & Land Cover Extents Across Indian States with TGA less than 43 L.ha. (2010-2011)

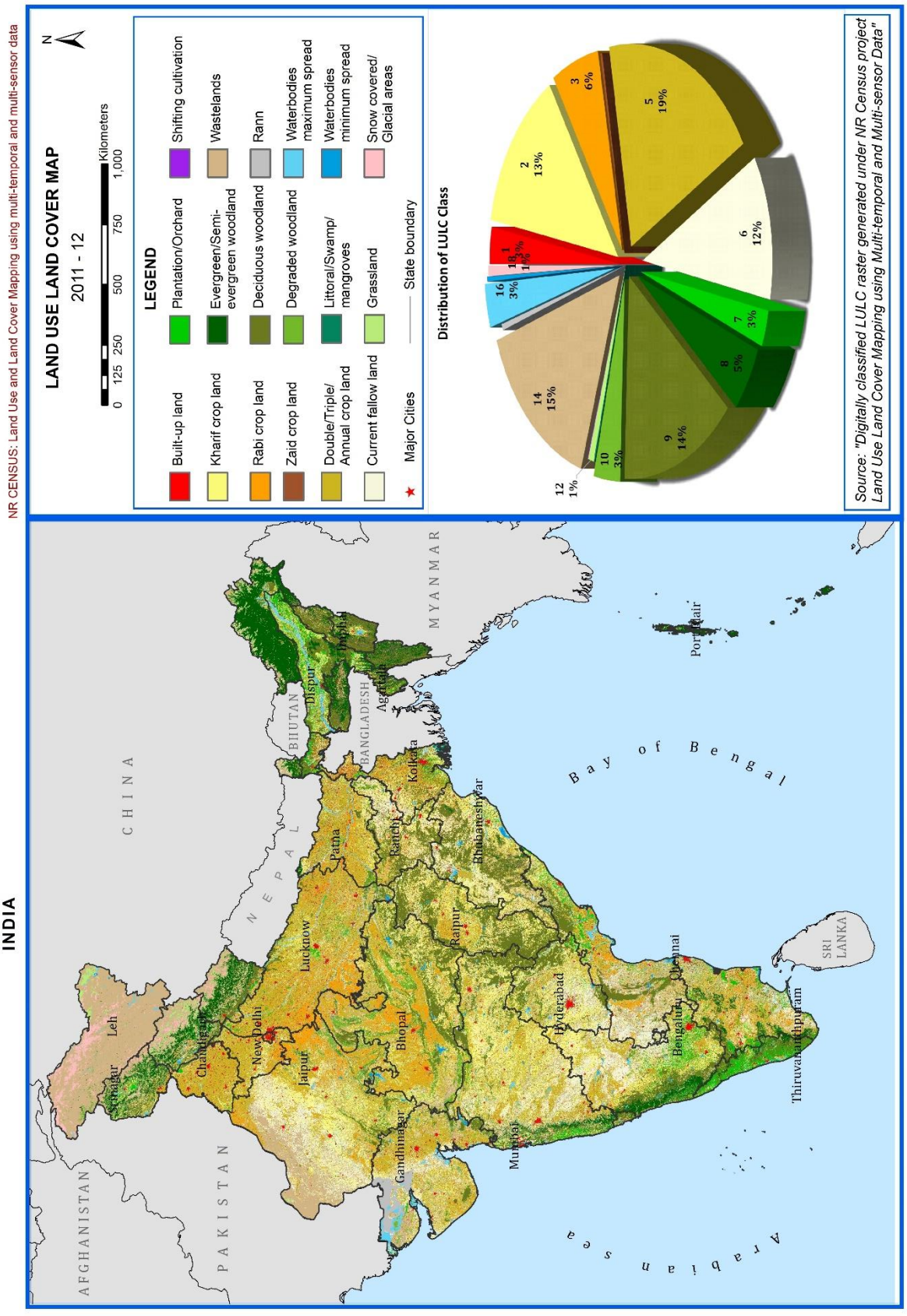

Figure 15- LULC map 2011-12

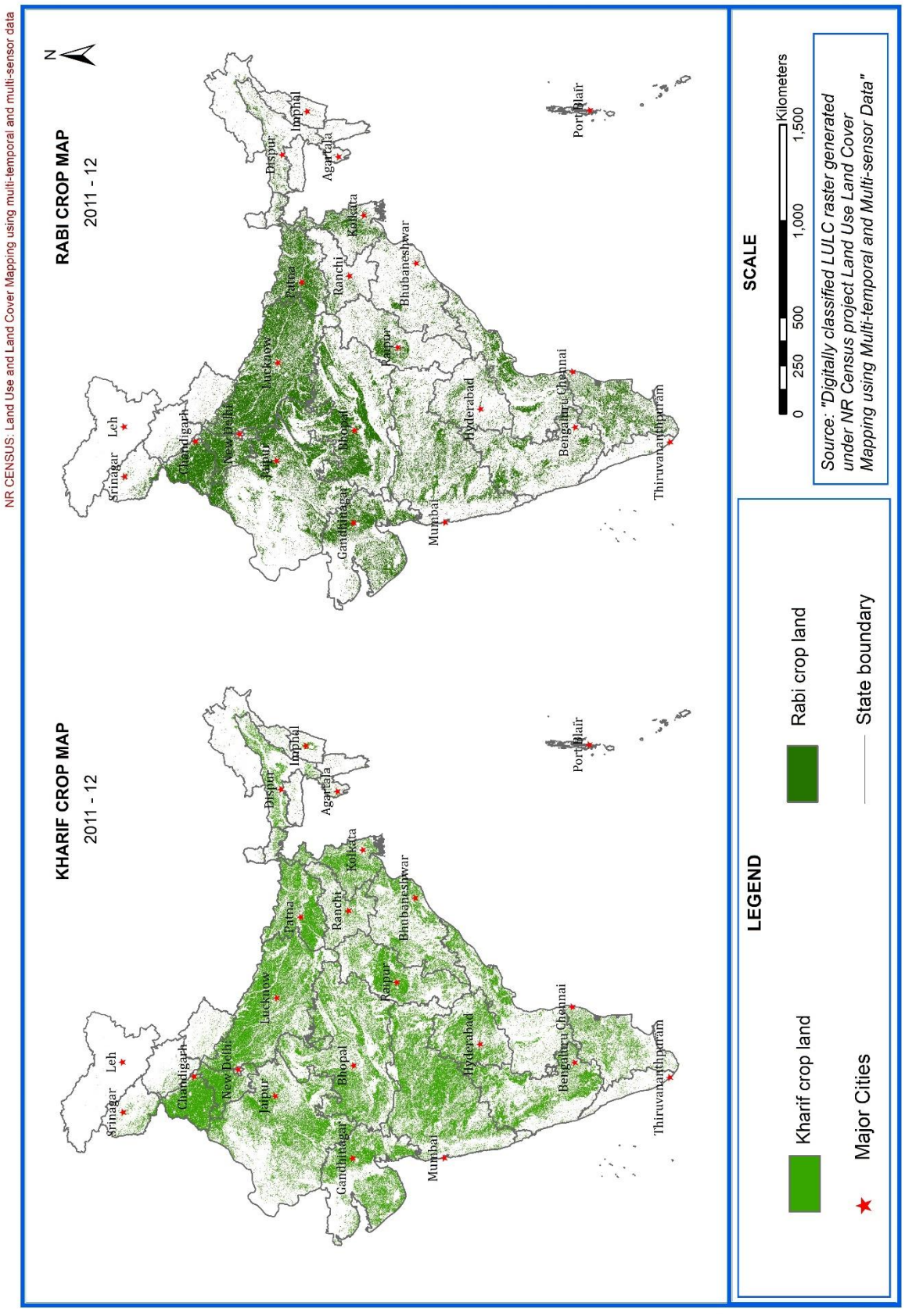

Figure 16- Crop map 2011-12

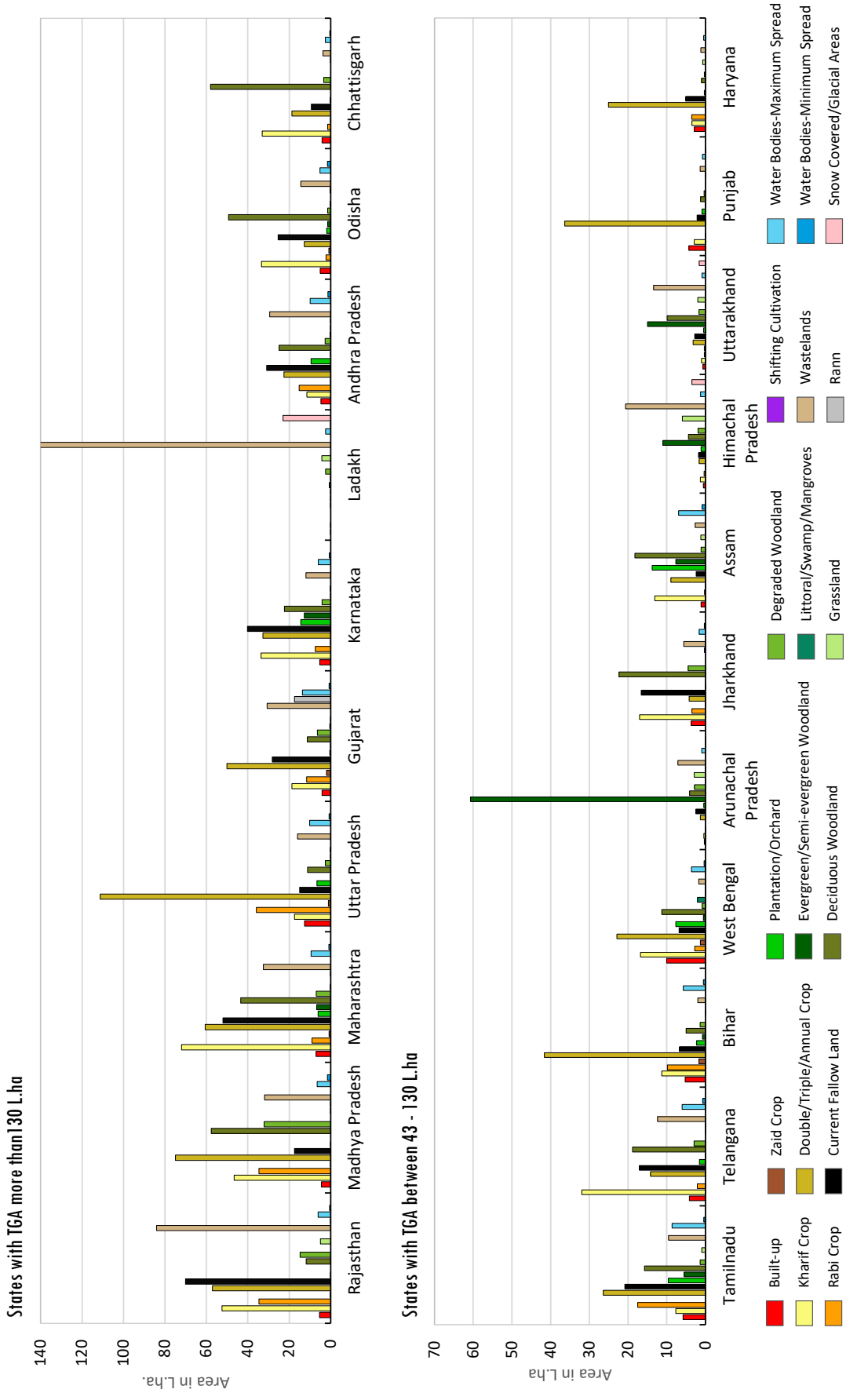

Chart 13- Distribution of Class-wise Land Use & Land Cover Extents Across Indian States with TGA greater than 43 L.ha. (2011-2012)

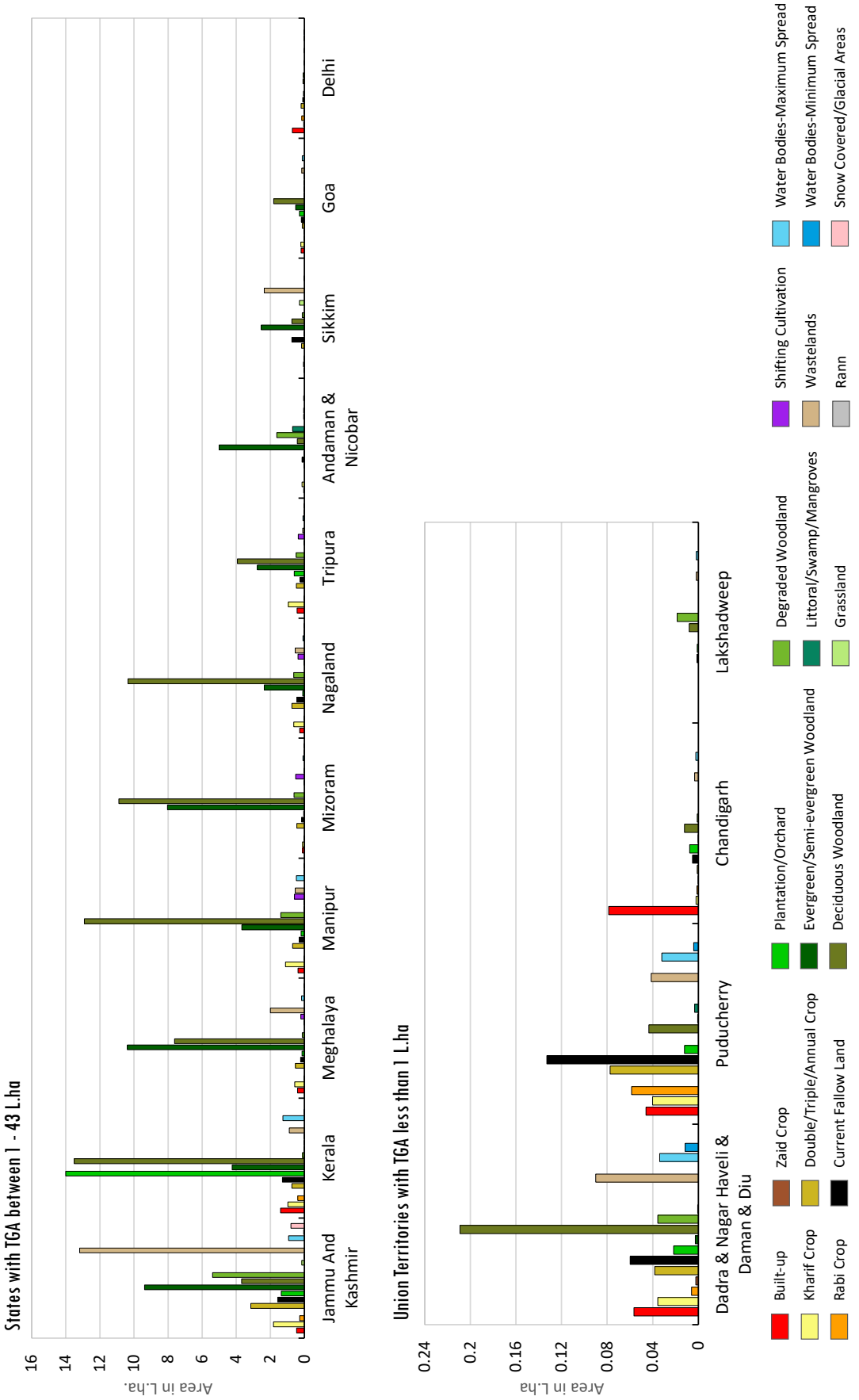

Chart 14- Distribution of Class-wise Land Use & Land Cover Extents Across Indian States with TGA less than 43 L.ha. (2011-2012)

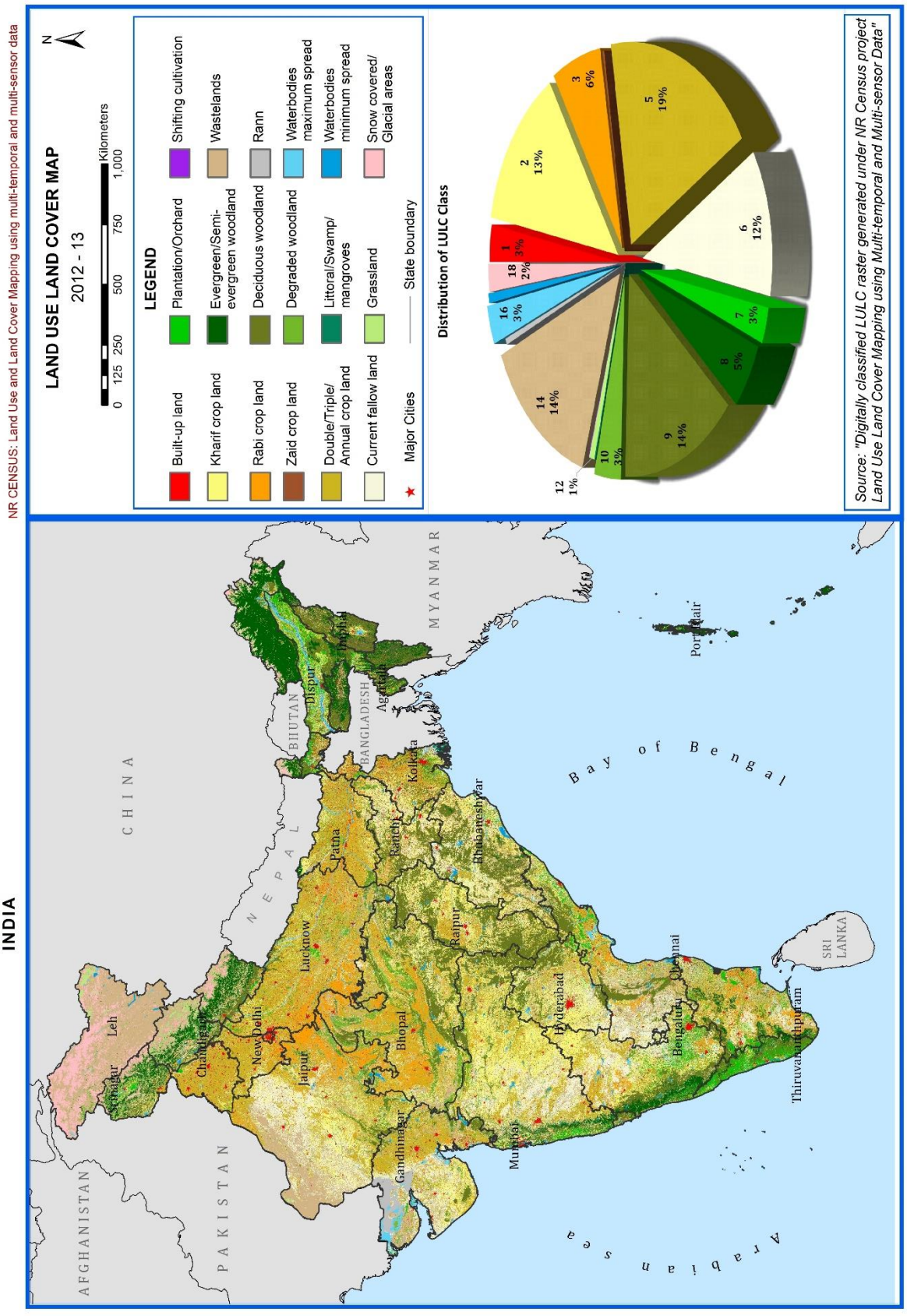

Figure 17- LULC map 2012-13

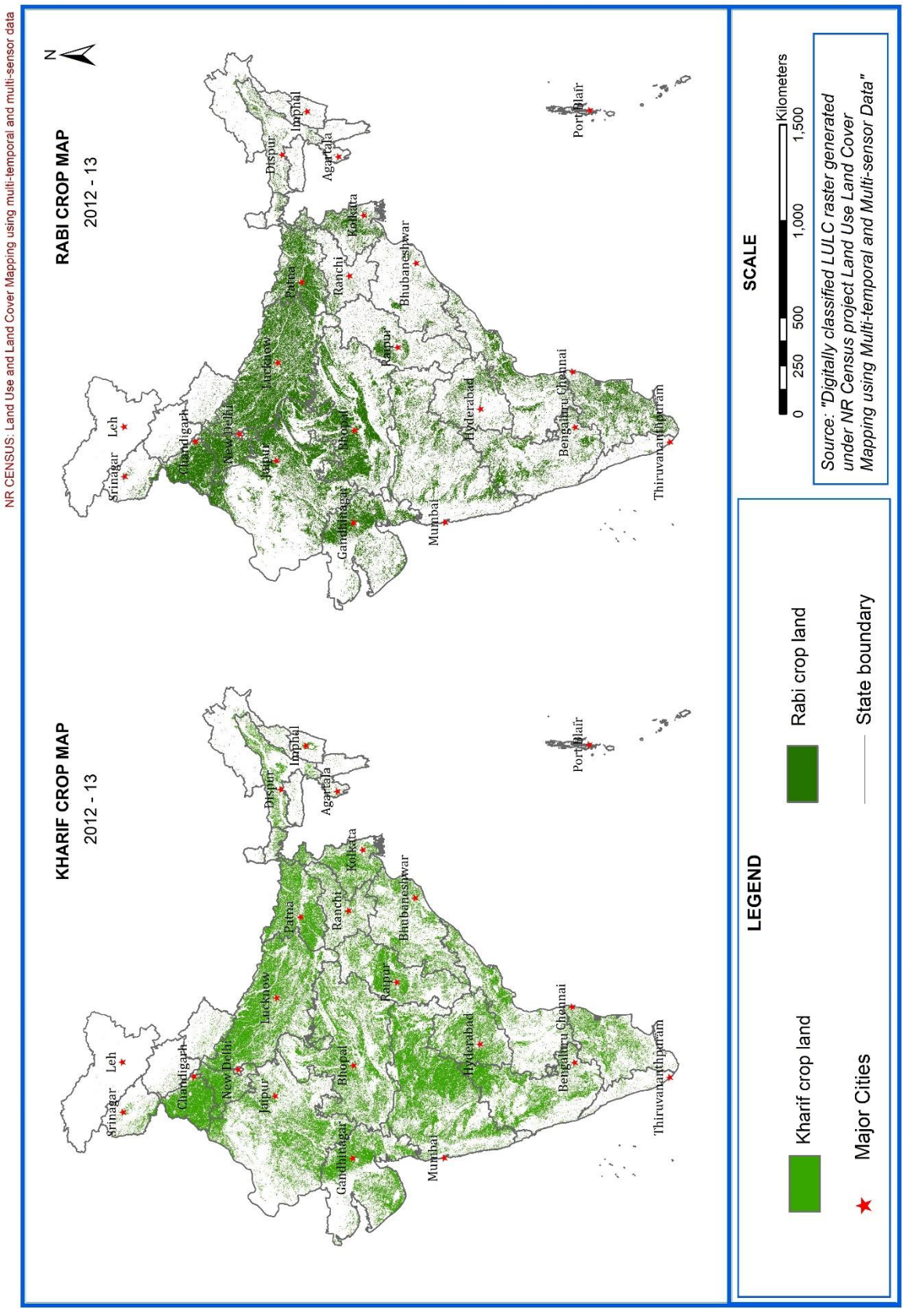

Figure 18- Crop map 2012-13

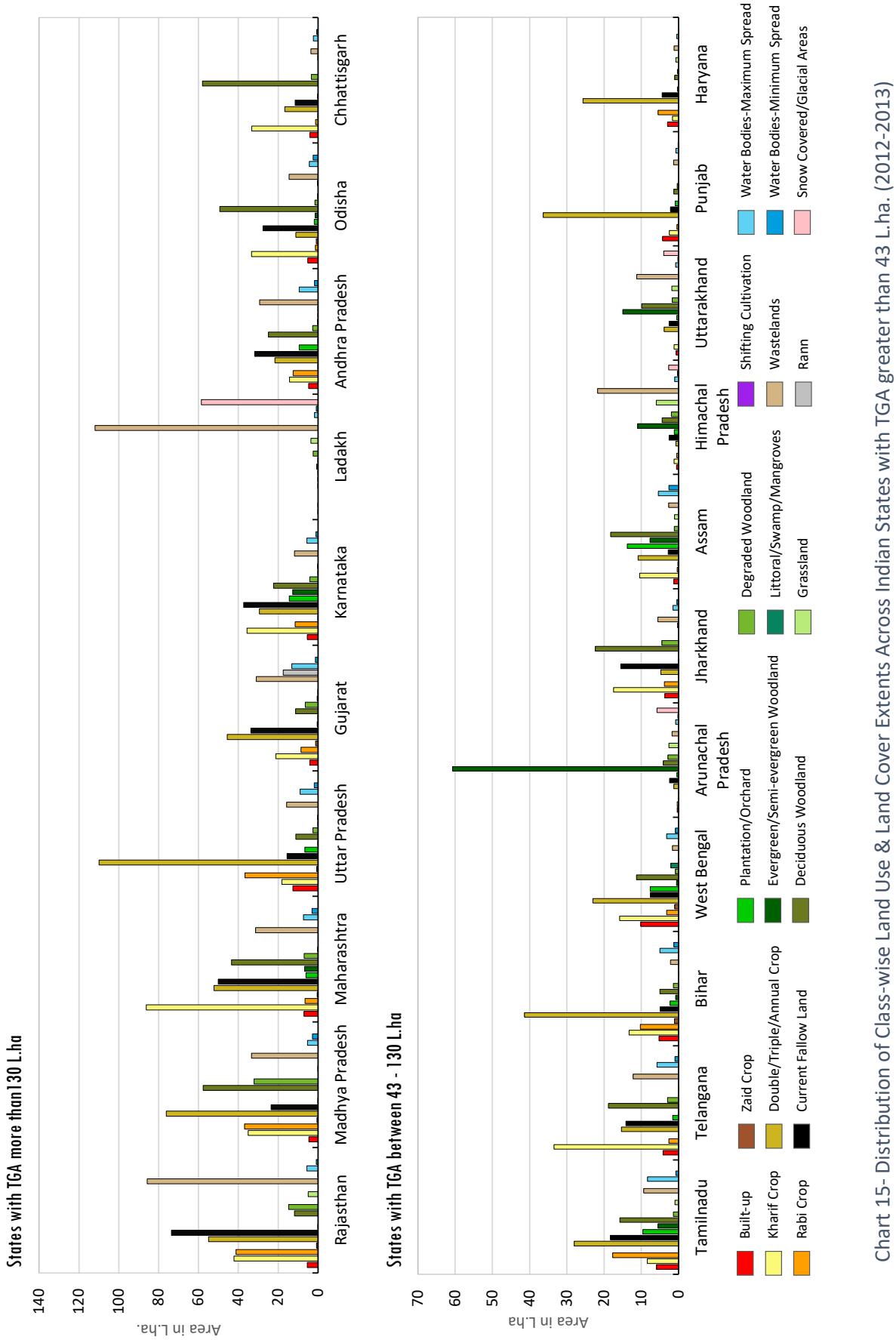

Chart 15- Distribution of Class-wise Land Use & Land Cover Extents Across Indian States with TGA greater than 43 L.ha. (2012-2013)

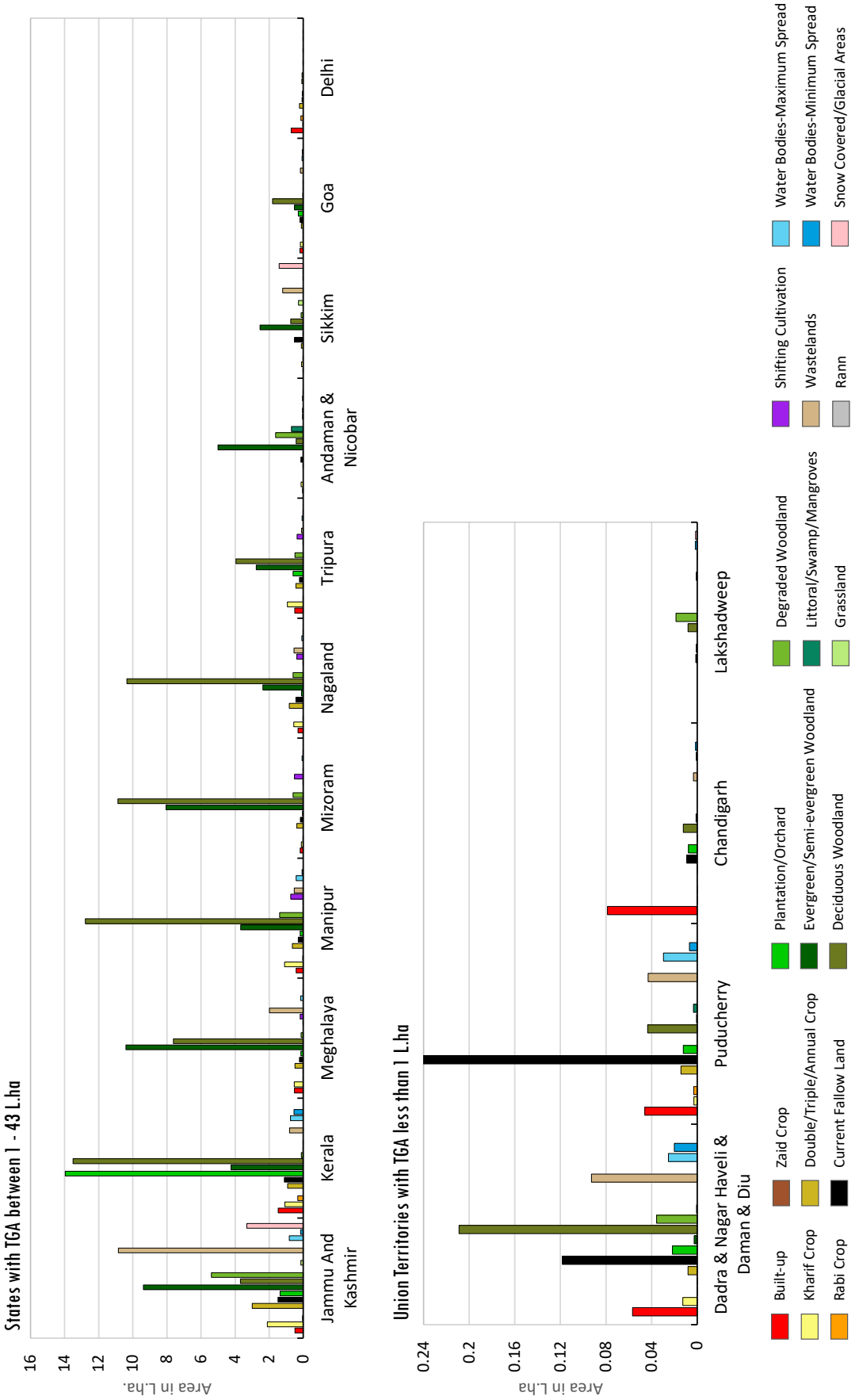

Chart 16- Distribution of Class-wise Land Use & Land Cover Extents Across Indian States with TGA less than 43 L.ha. (2012-2013)

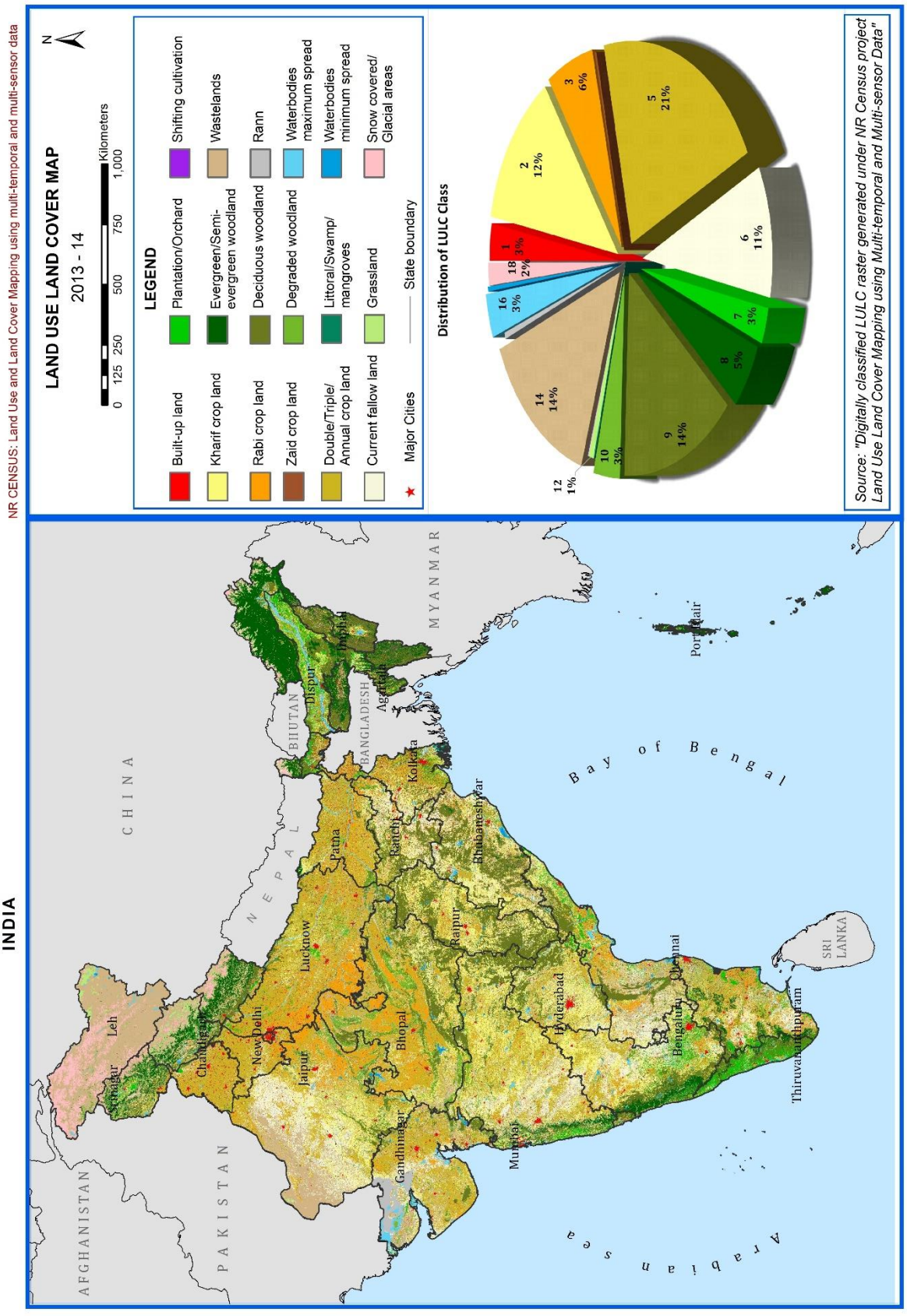

Figure 19- LULC map 2013-14

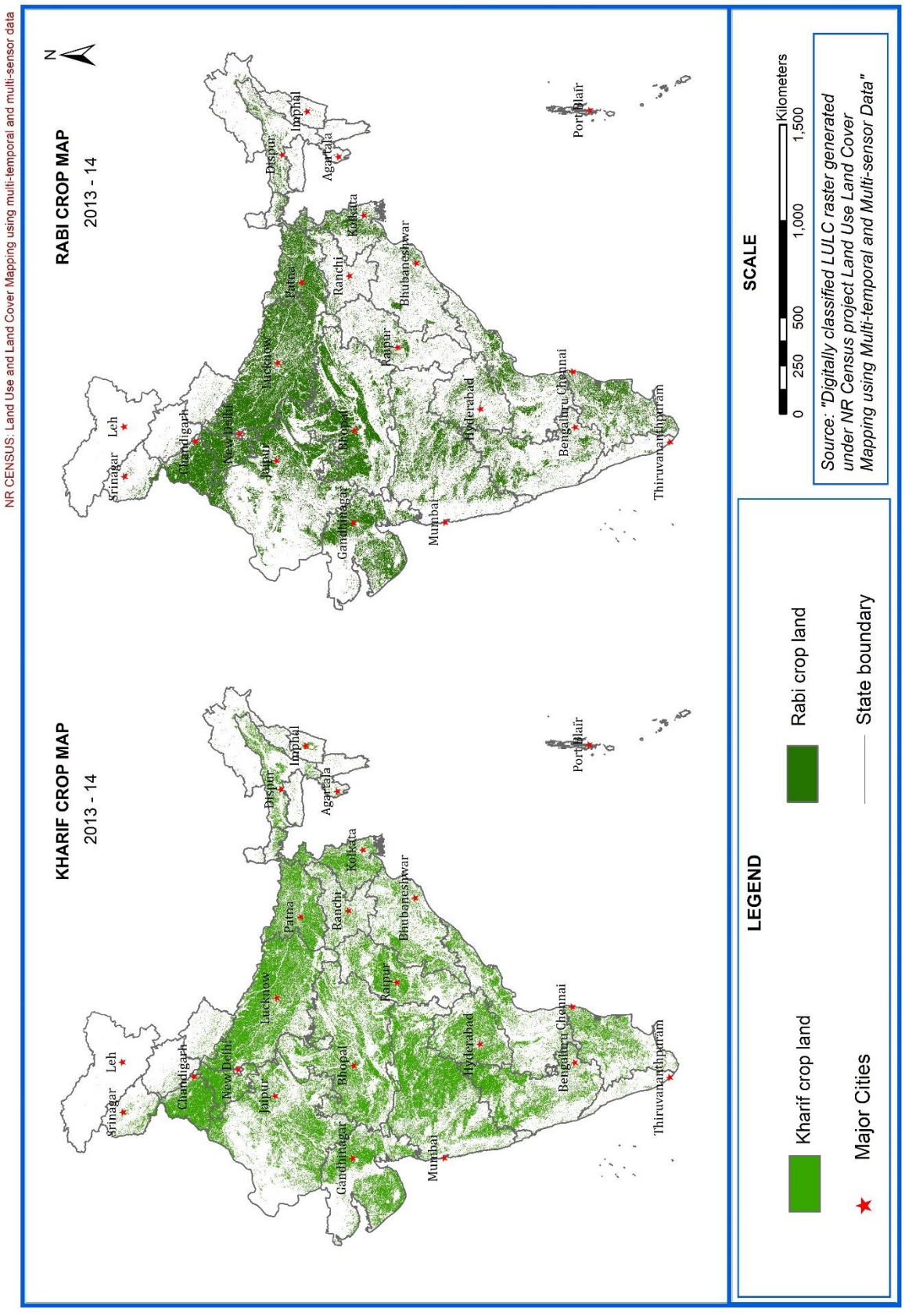

Figure 20- Crop map 2013-14

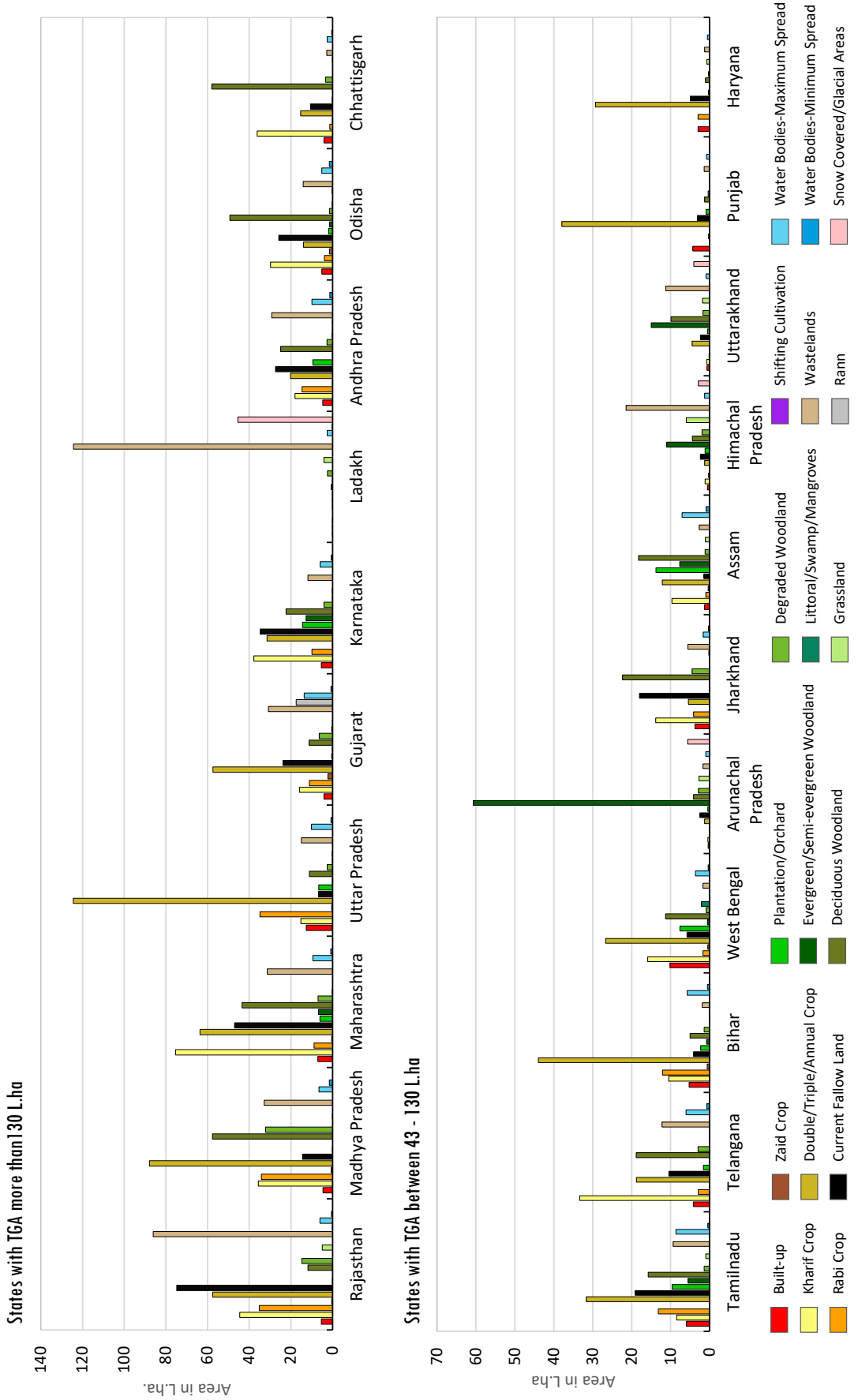

Chart 17- Distribution of Class-wise Land Use & Land Cover Extents Across Indian States with TGA greater than 43 L.ha. (2013-2014)

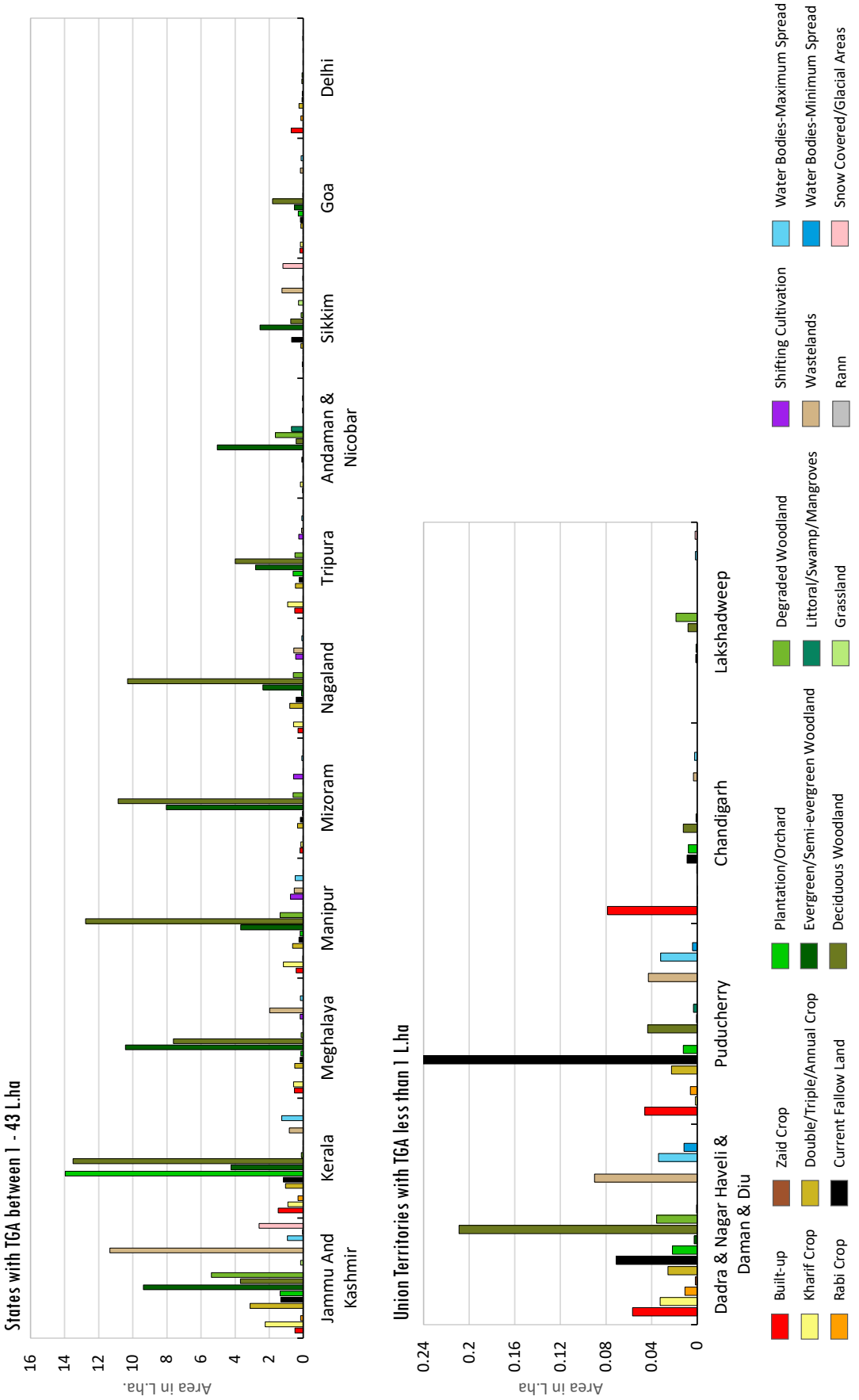

Chart 18- Distribution of Class-wise Land Use & Land Cover Extents Across Indian States with TGA less than 43 L.ha. (2013-2014)

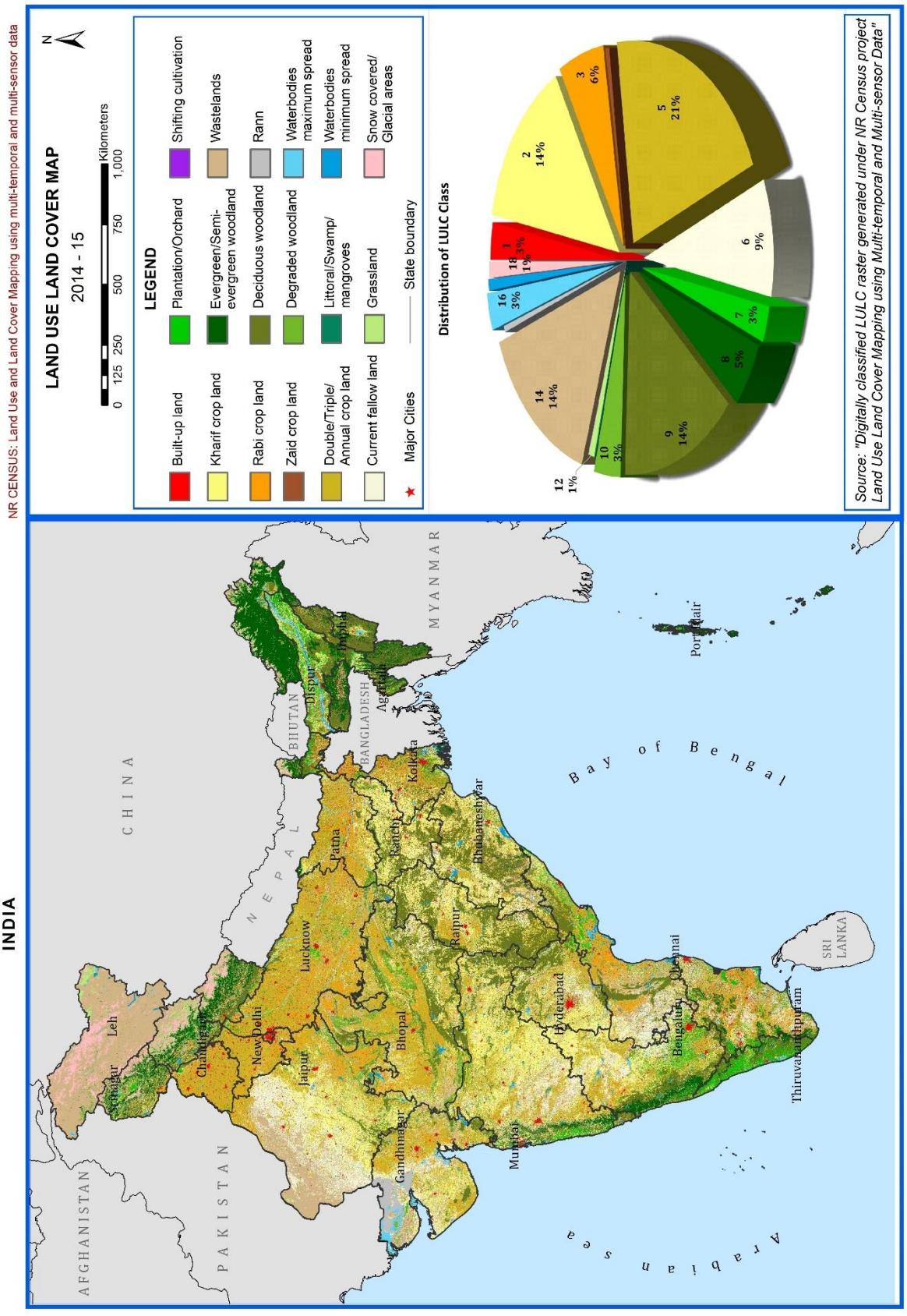

Figure 21- LULC map 2014-15

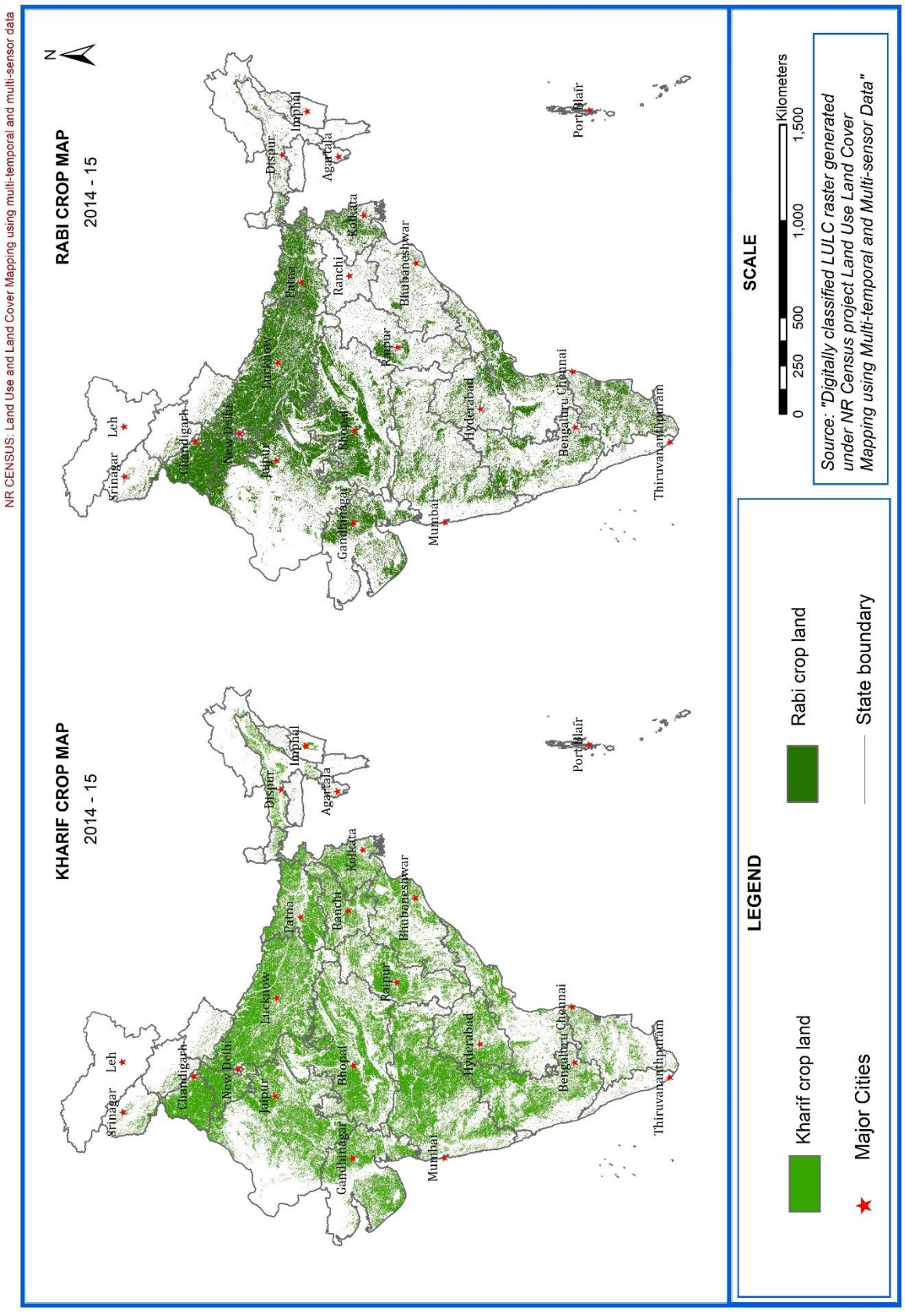

Figure 22- Crop map 2014-15

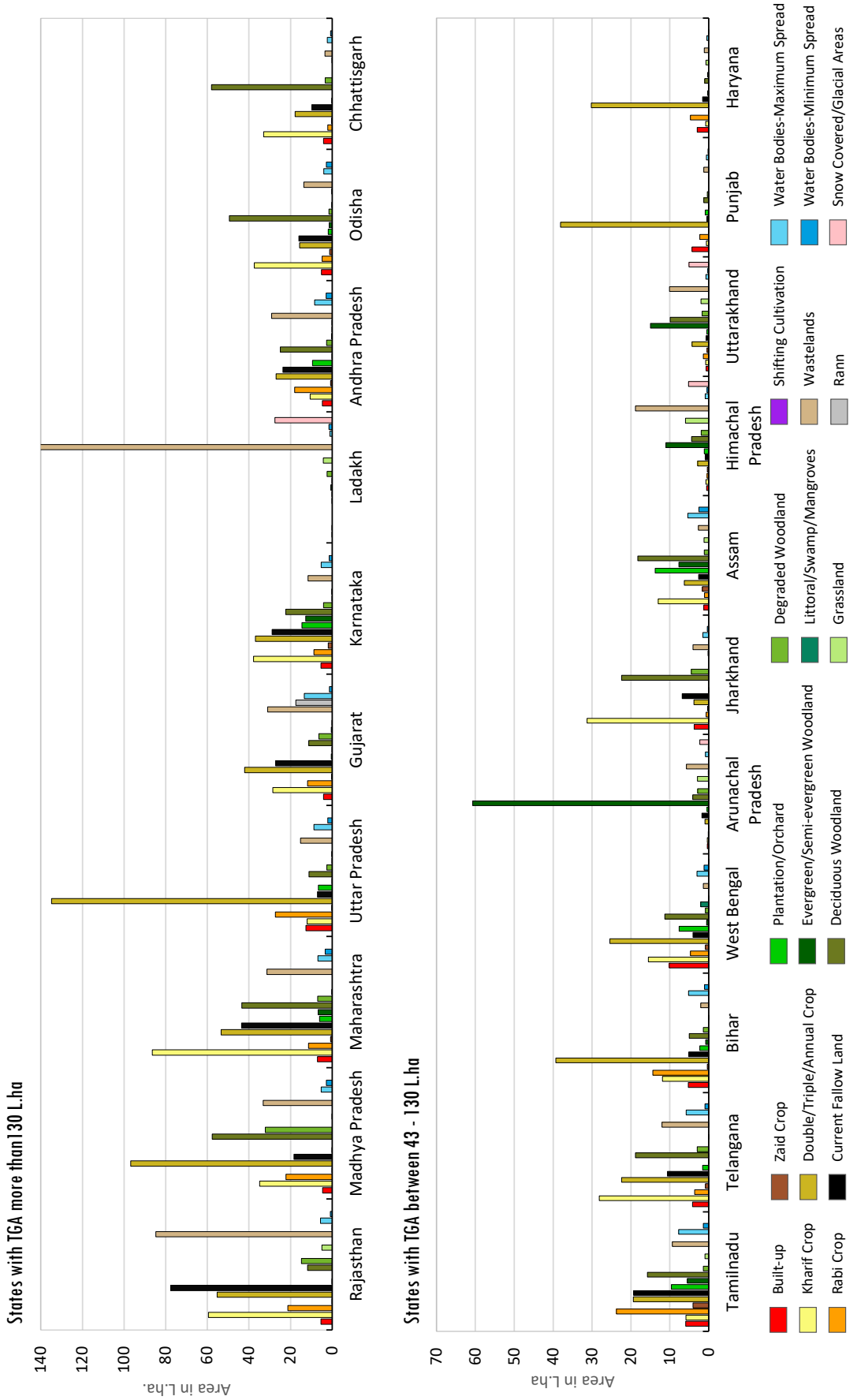

Chart 19- Distribution of Class-wise Land Use & Land Cover Extents Across Indian States with TGA greater than 43 L.ha. (2014-2015)

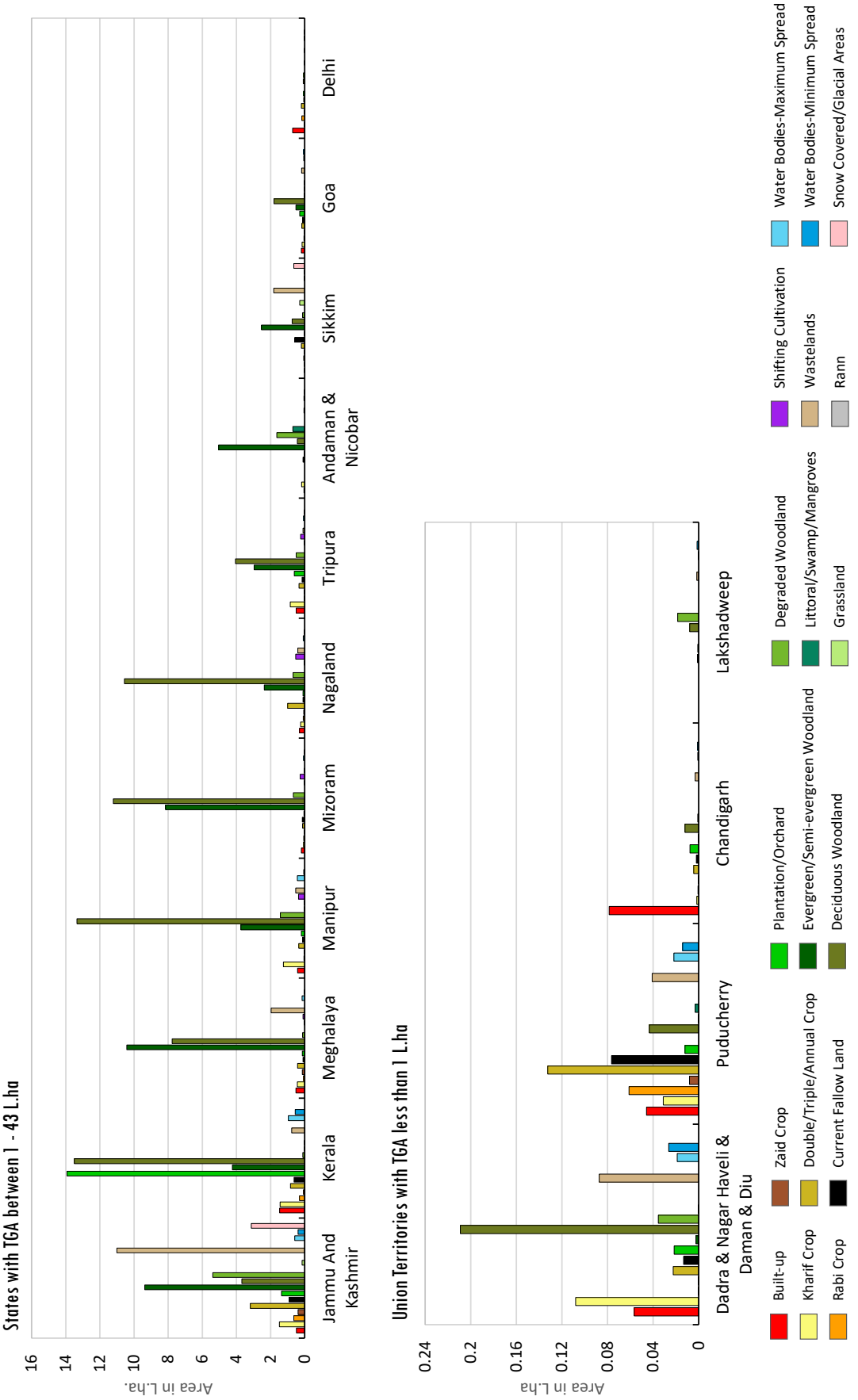

Chart 20- Distribution of Class-wise Land Use & Land Cover Extents Across Indian States with TGA less than 43 L.ha. (2014-2015)

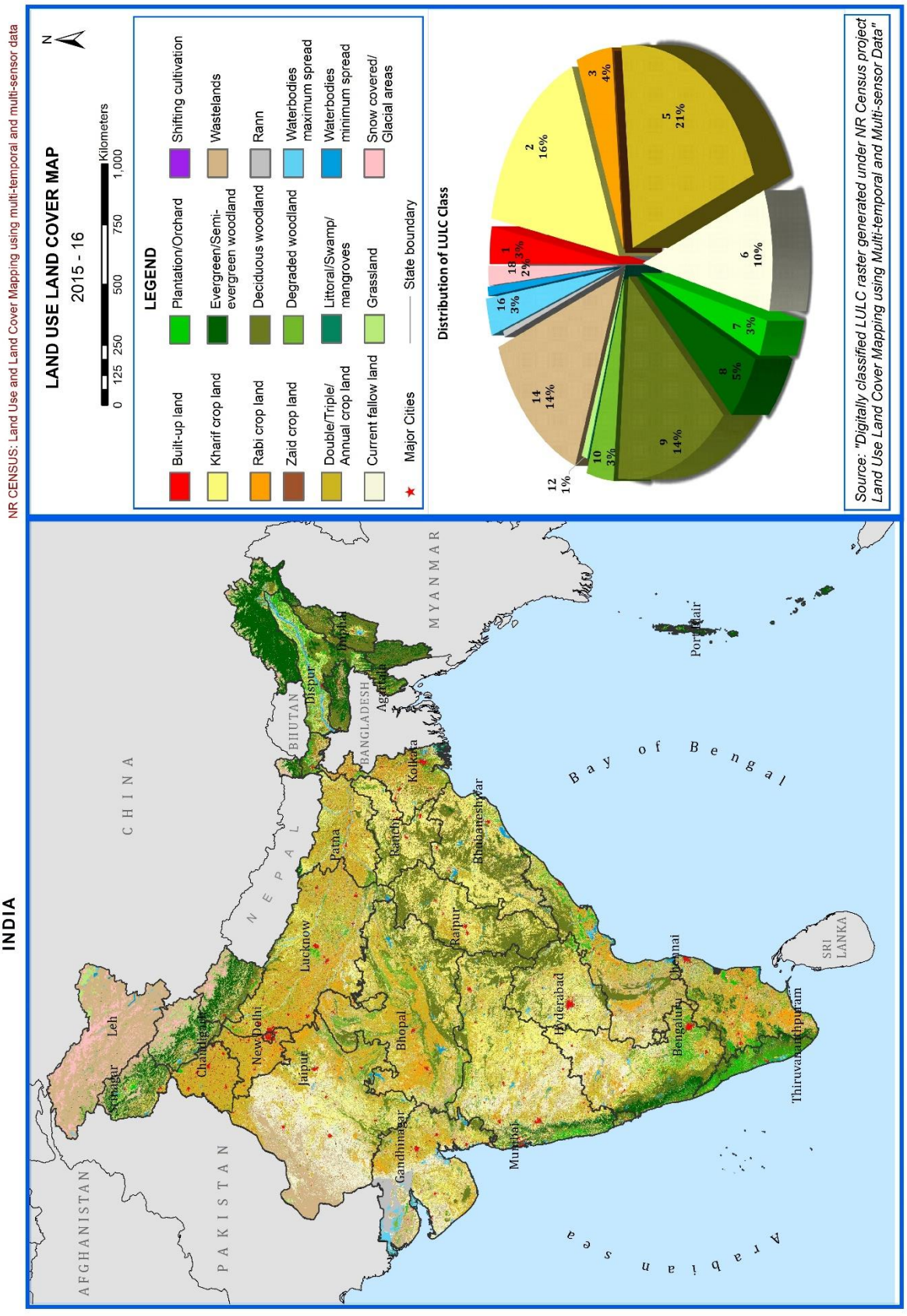

Figure 23- LULC map 2015-16

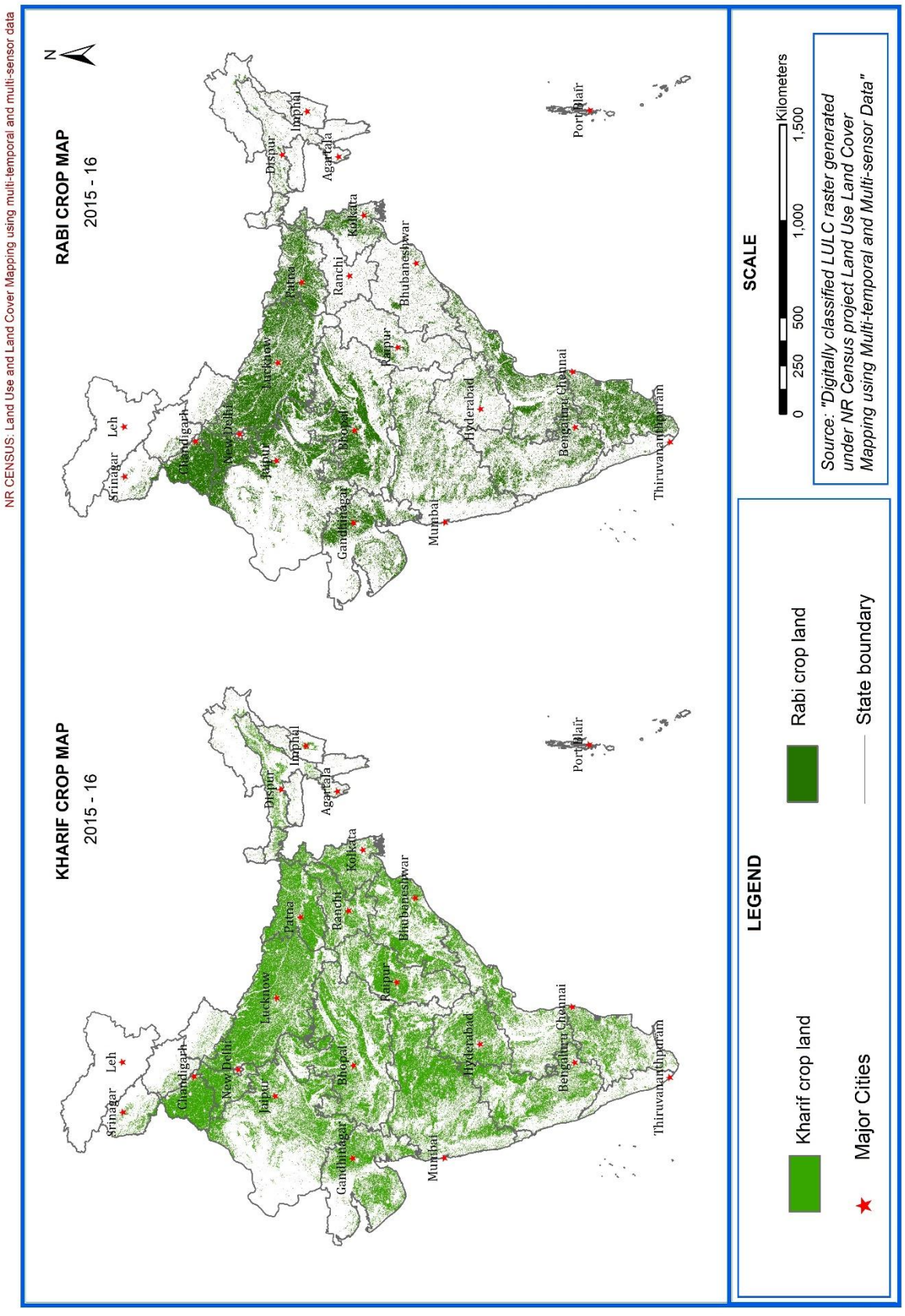

Figure 24- Crop map 2015-16

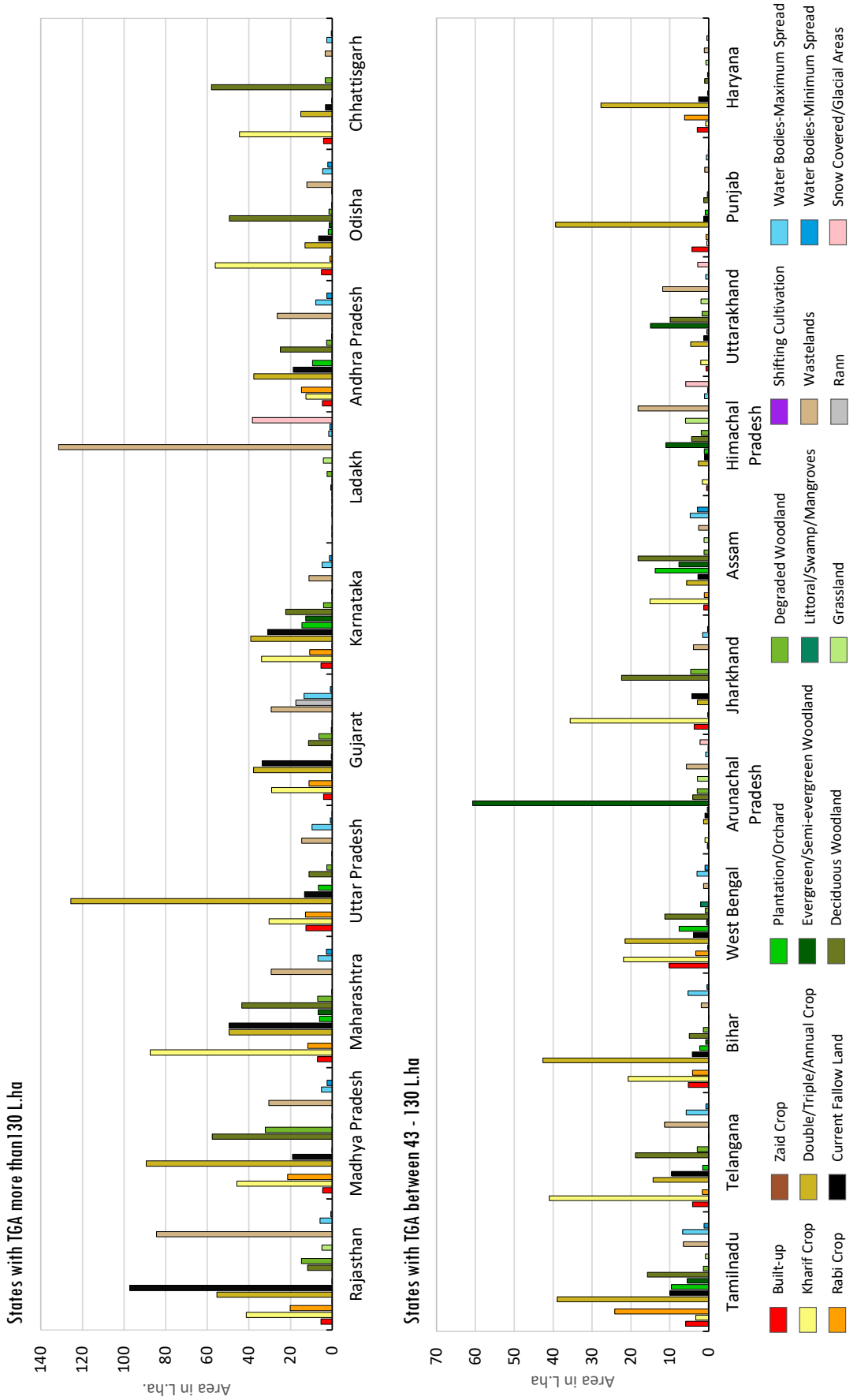

Chart 21- Distribution of Class-wise Land Use & Land Cover Extents Across Indian States with TGA greater than 43 L.ha. (2015-2016)

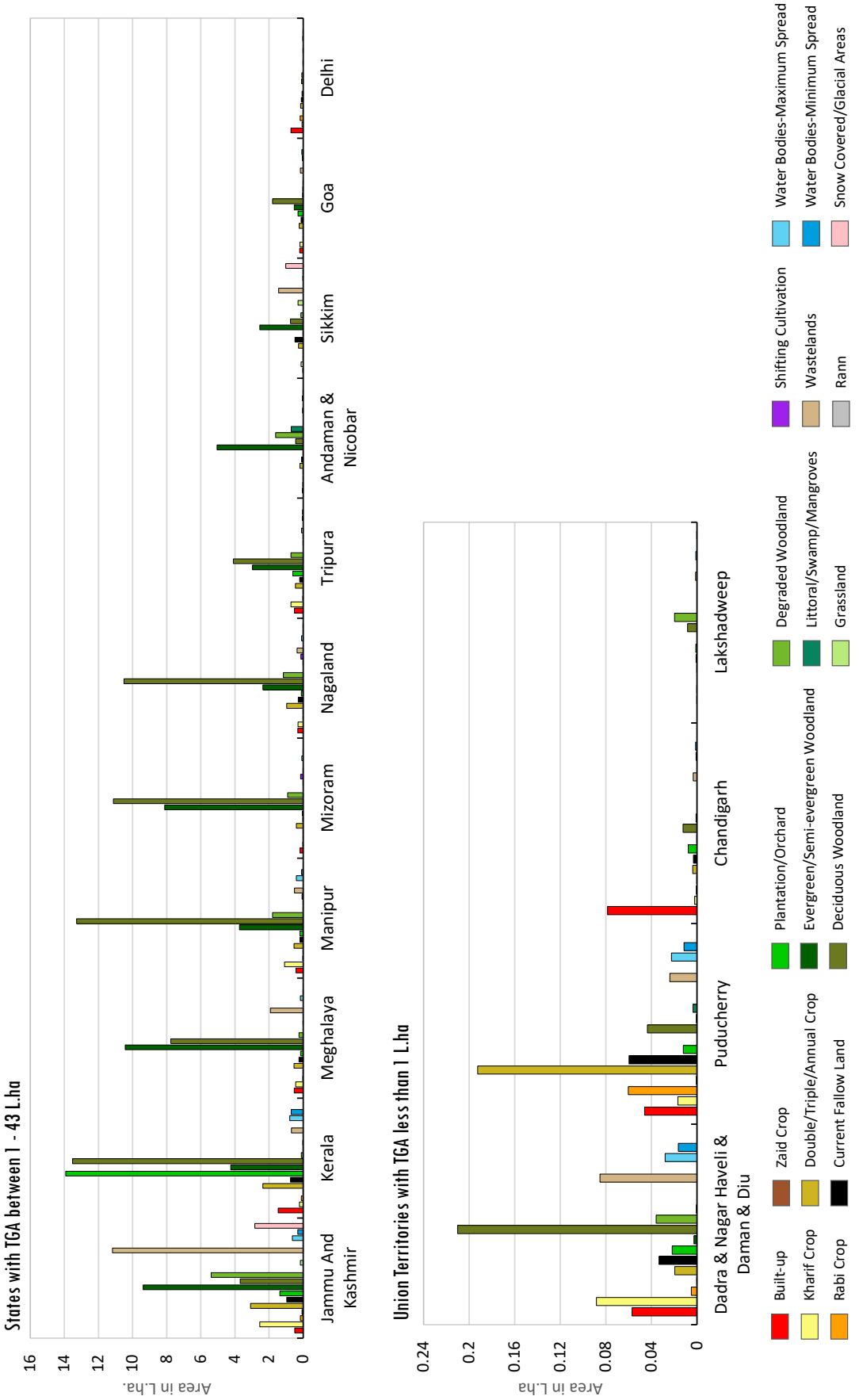

Chart 22- Distribution of Class-wise Land Use & Land Cover Extents Across Indian States with TGA less than 43 L.ha. (2015-2016)

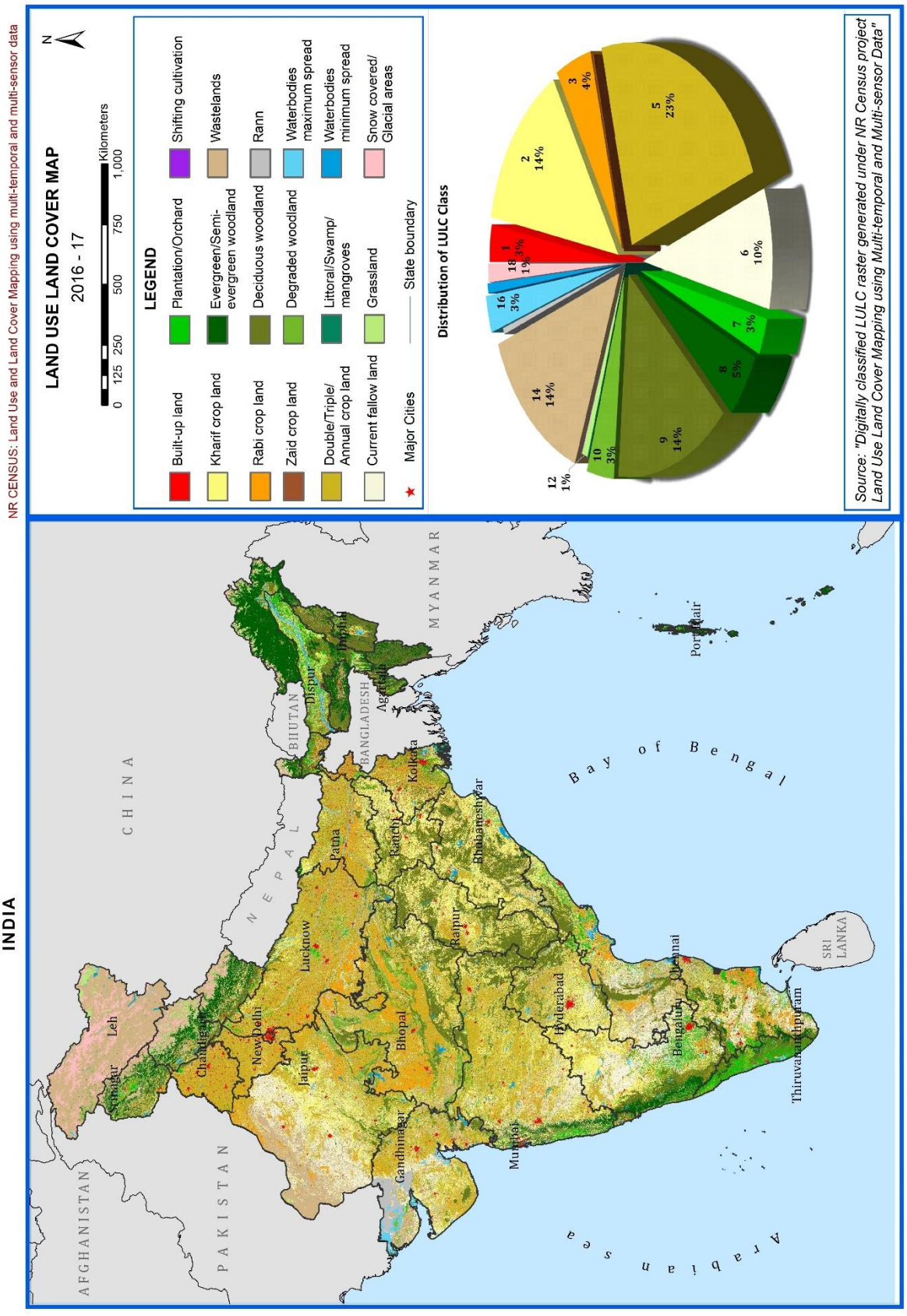

Figure 25- LULC map 2016-17

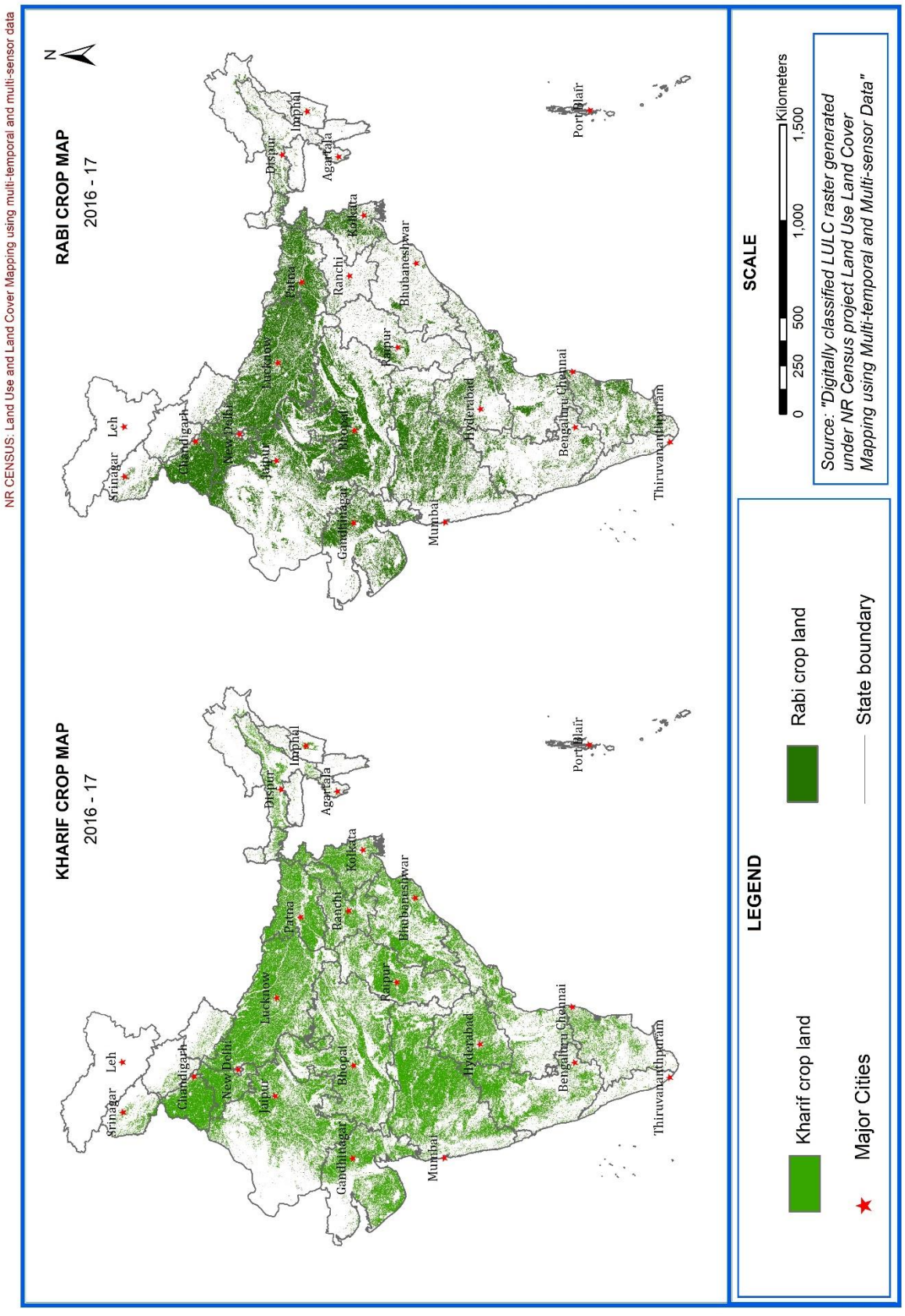

Figure 26- Crop map 2016-17

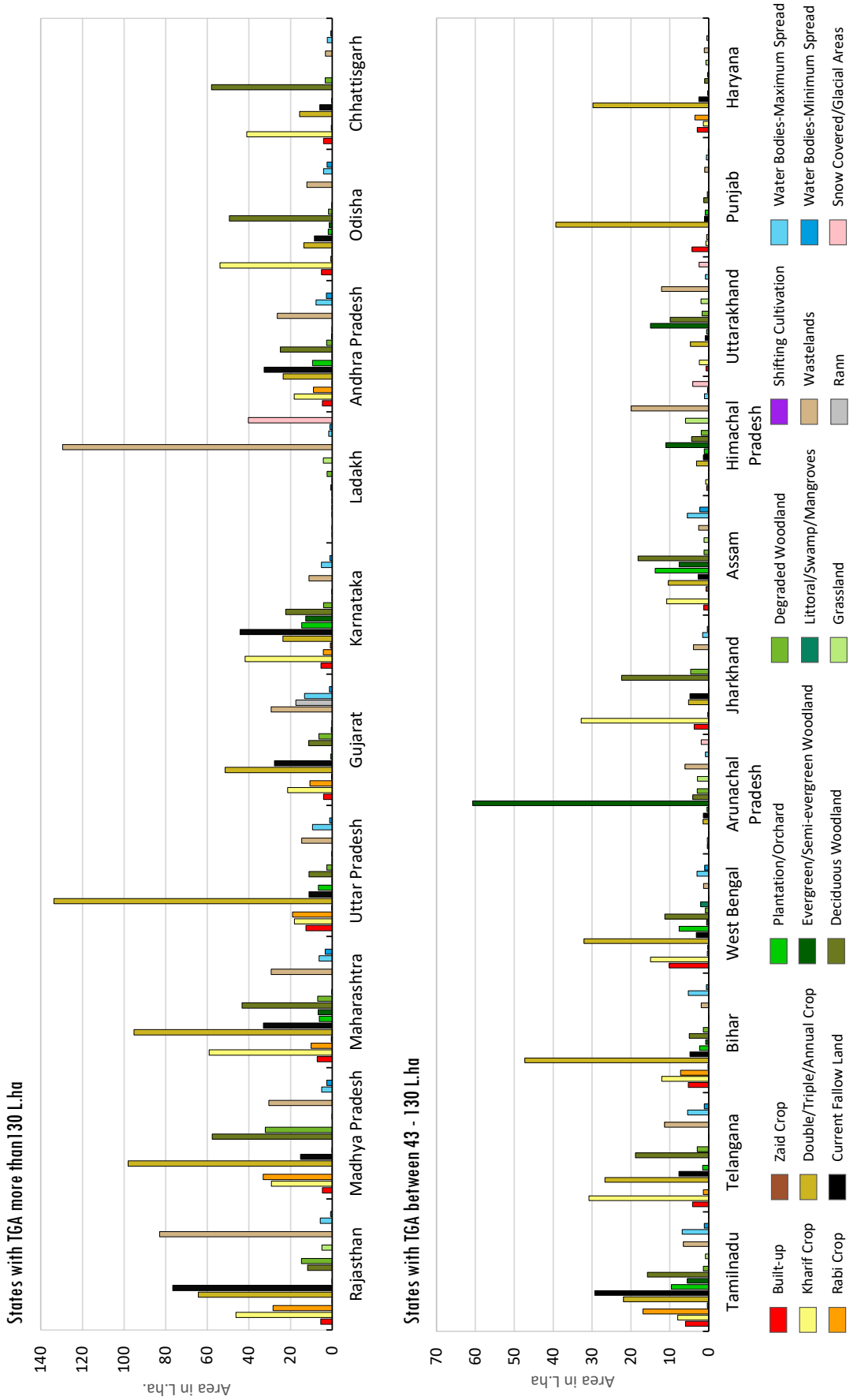

Chart 23- Distribution of Class-wise Land Use & Land Cover Extents Across Indian States with TGA greater than 43 L.ha. (2016-2017)

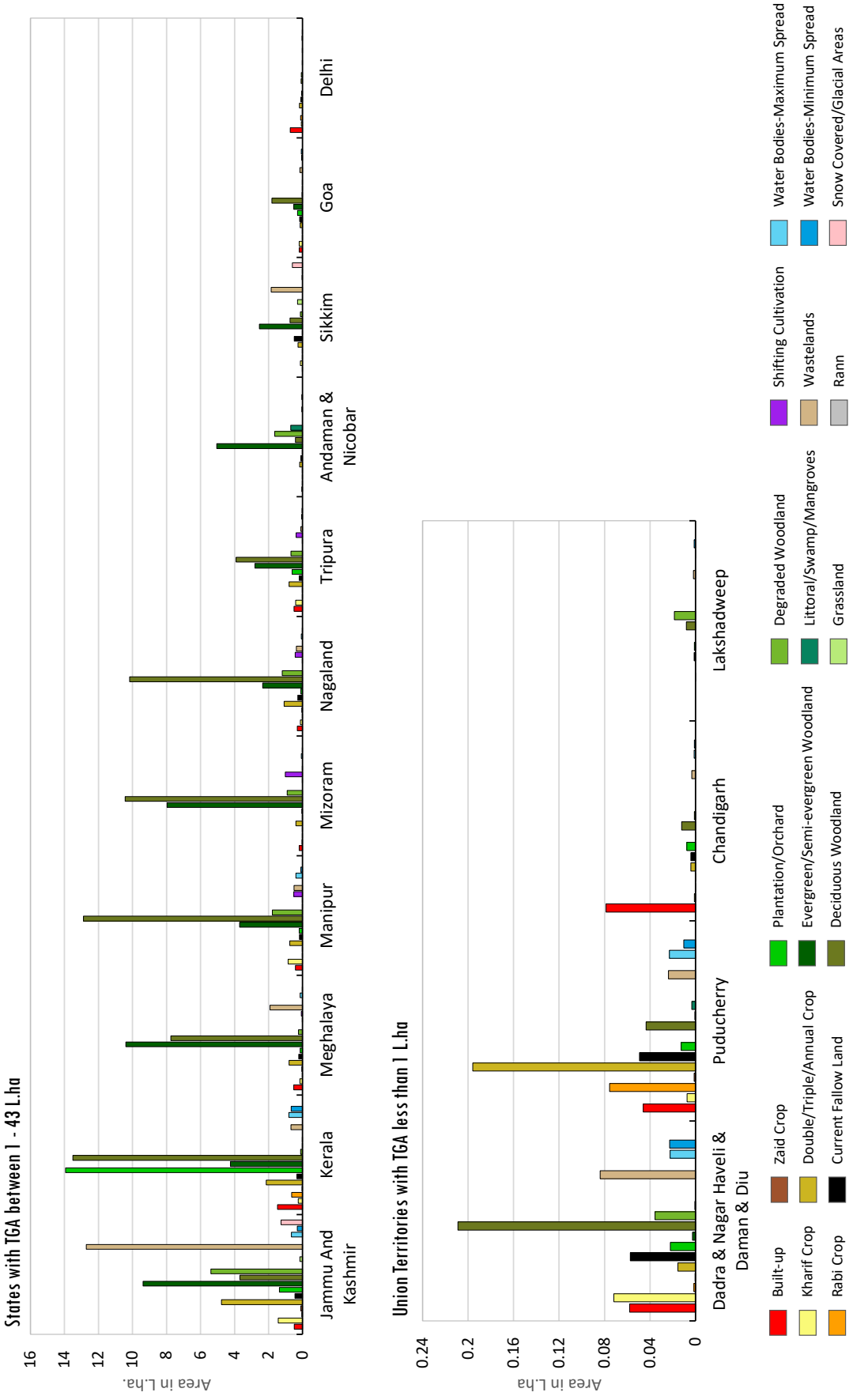

Chart 24- Distribution of Class-wise Land Use & Land Cover Extents Across Indian States with TGA less than 43 L.ha. (2016-2017)

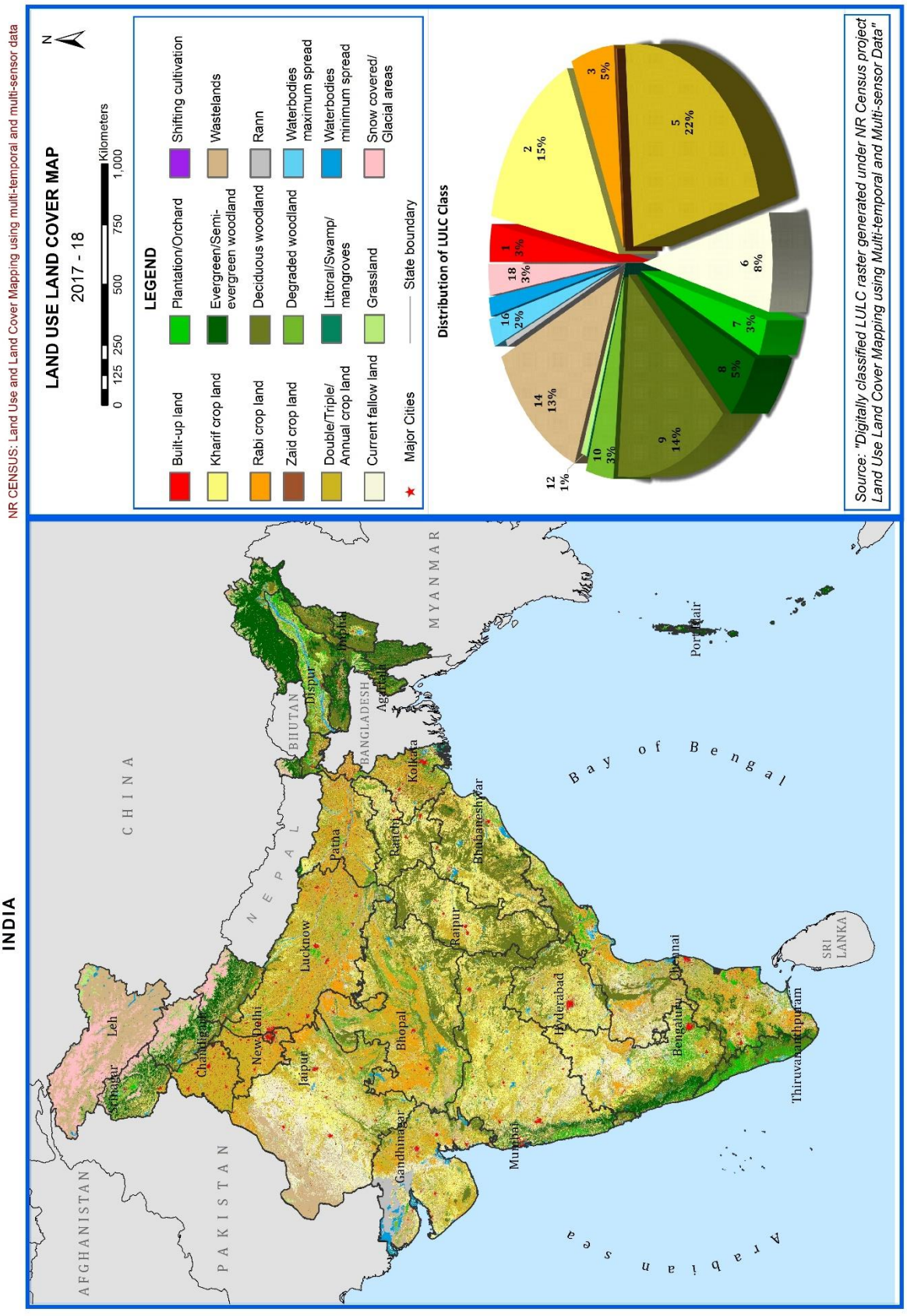

Figure 27- LULC map 2017-18

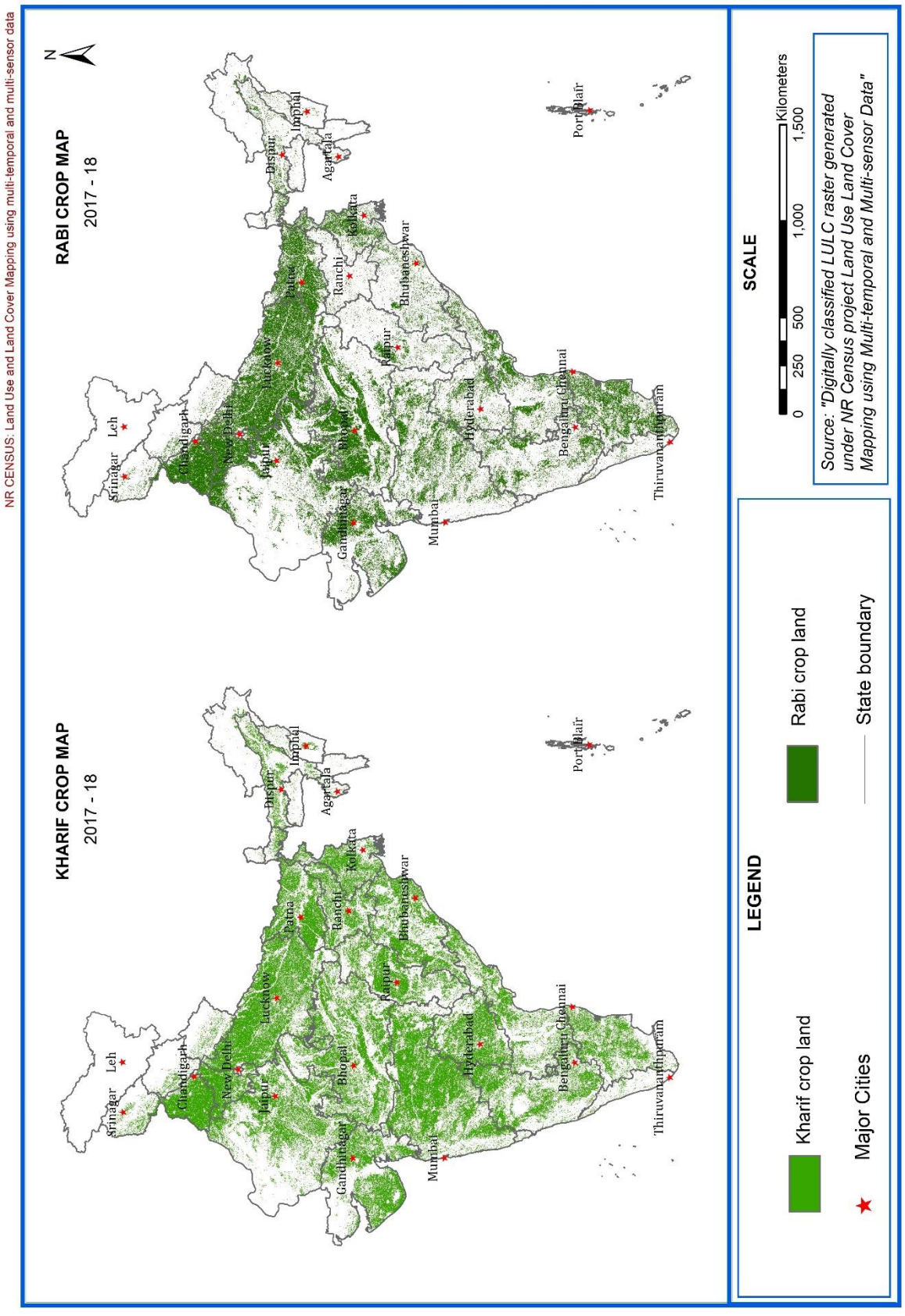

Figure 28- Crop map 2017-18

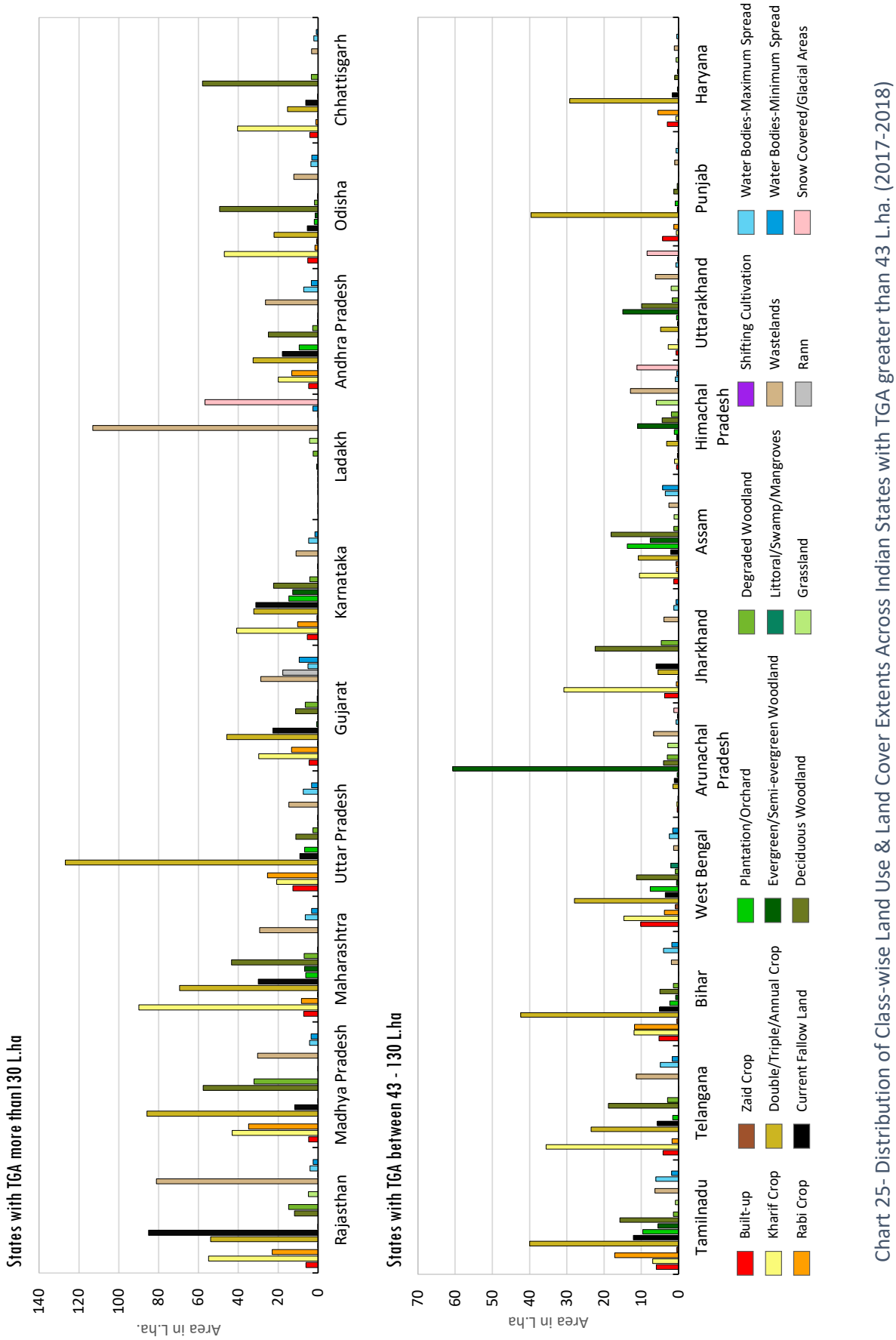

Chart 25- Distribution of Class-wise Land Use & Land Cover Extents Across Indian States with TGA greater than 43 L.ha. (2017-2018)

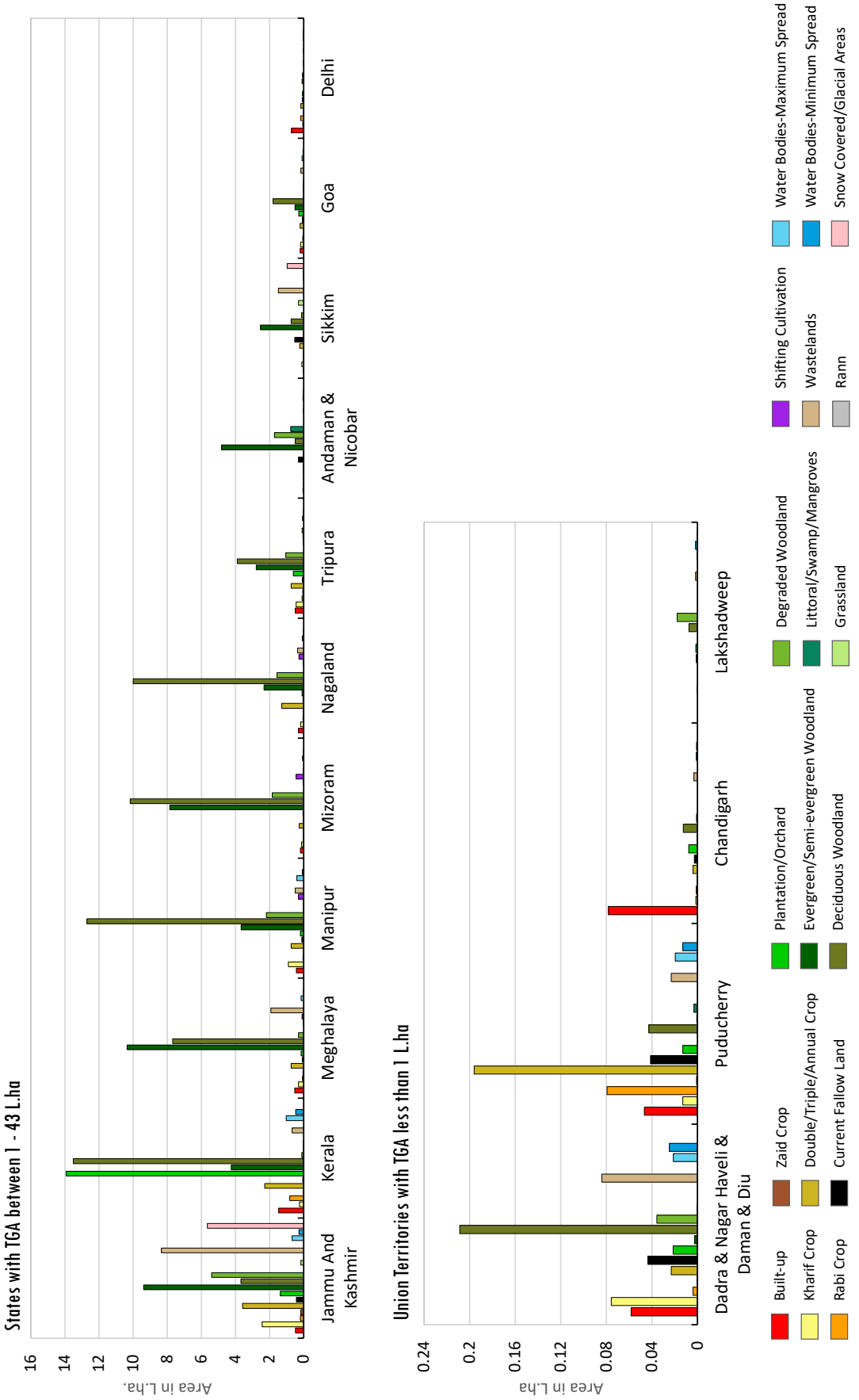

Chart 26- Distribution of Class-wise Land Use & Land Cover Extents Across Indian States with TGA less than 43 L.ha. (2017-2018)

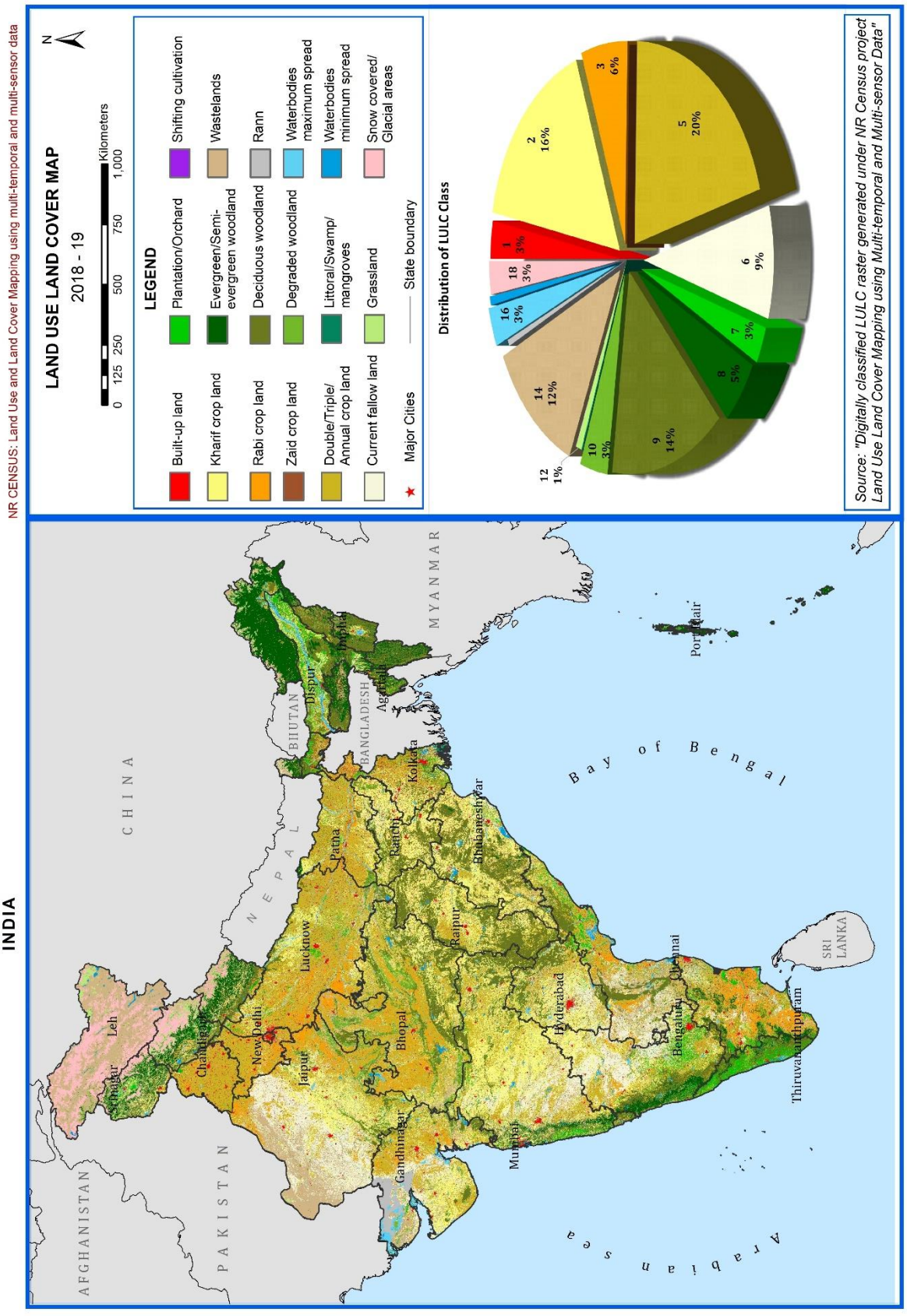

Figure 29- LULC map 2018-19

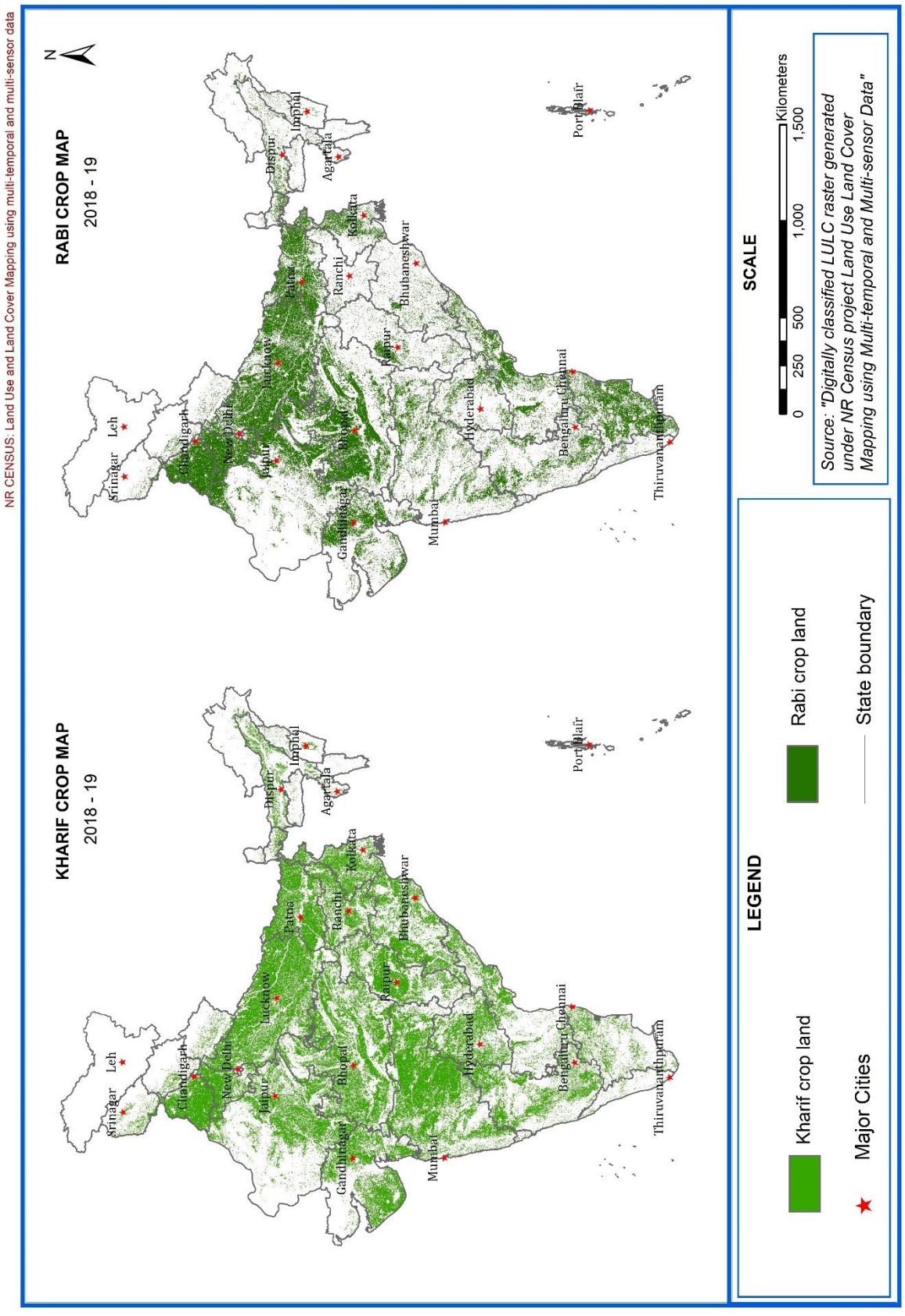

Figure 30- Crop map 2018-19

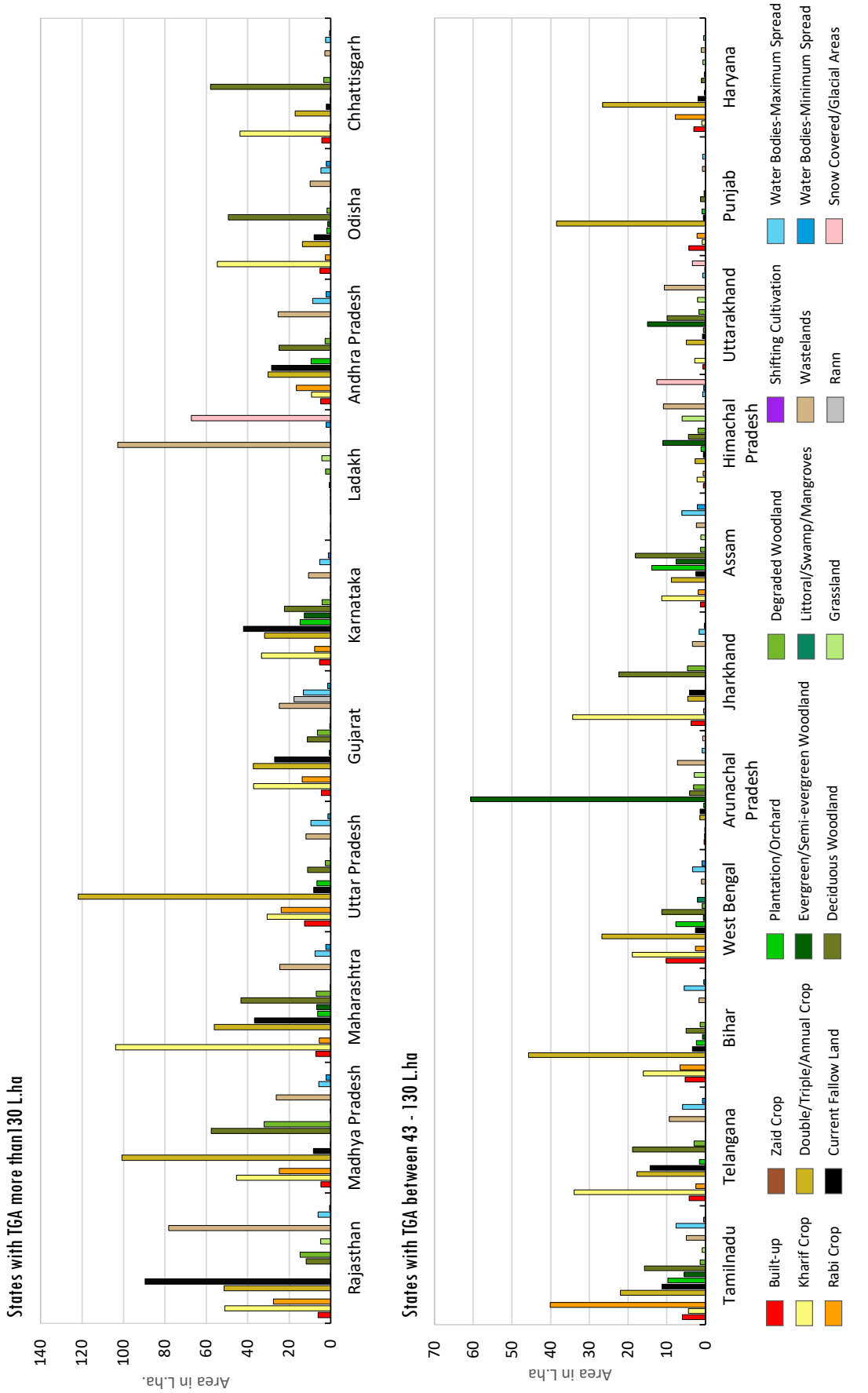

Chart 27- Distribution of Class-wise Land Use & Land Cover Extents Across Indian States with TGA greater than 43 L.ha. (2018-2019)

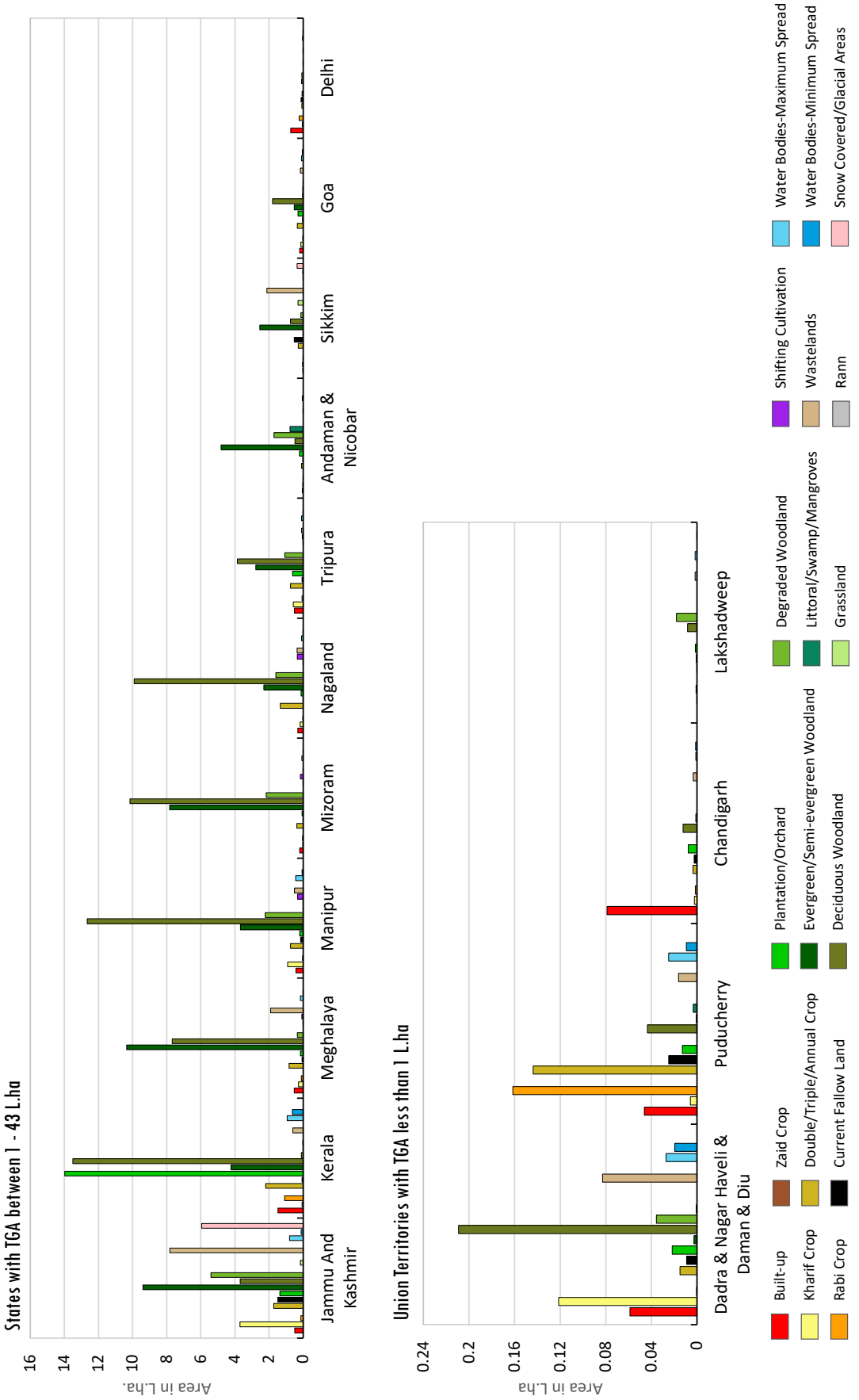

Chart 28- Distribution of Class-wise Land Use & Land Cover Extents Across Indian States with TGA less than 43 L.ha. (2018-2019)

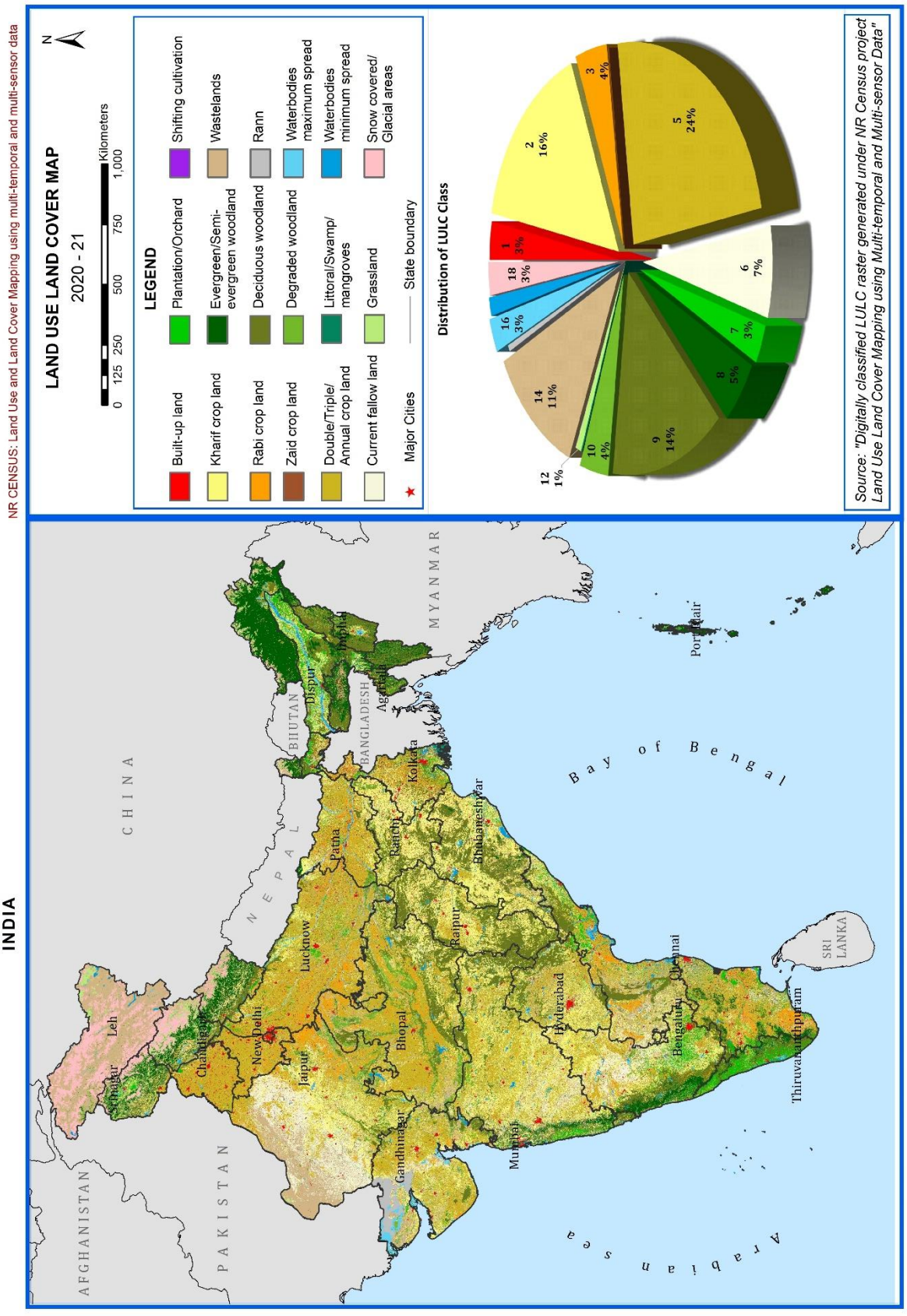

Figure 31- LULC map 2020-21

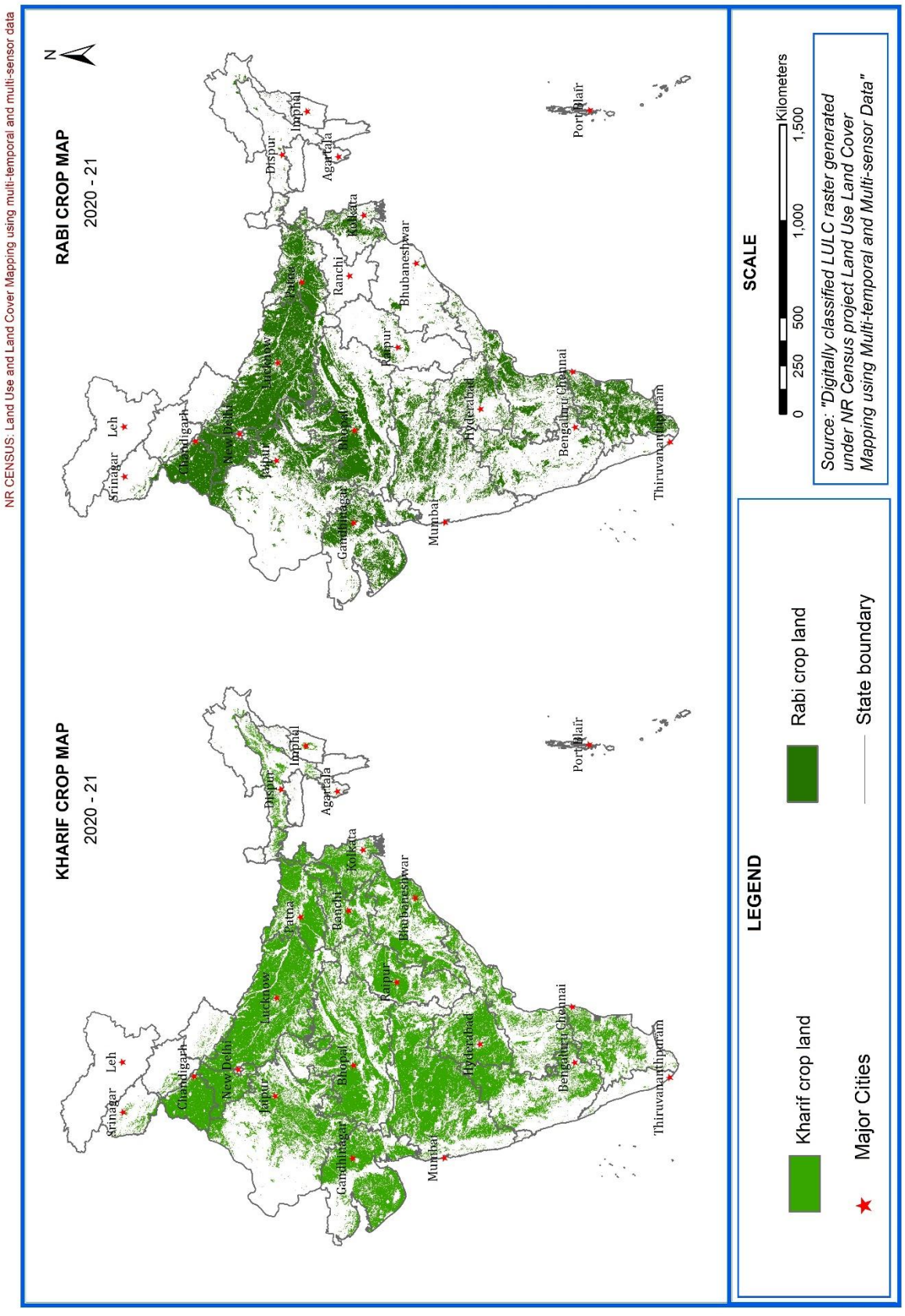

Figure 32- Crop map 2020-21

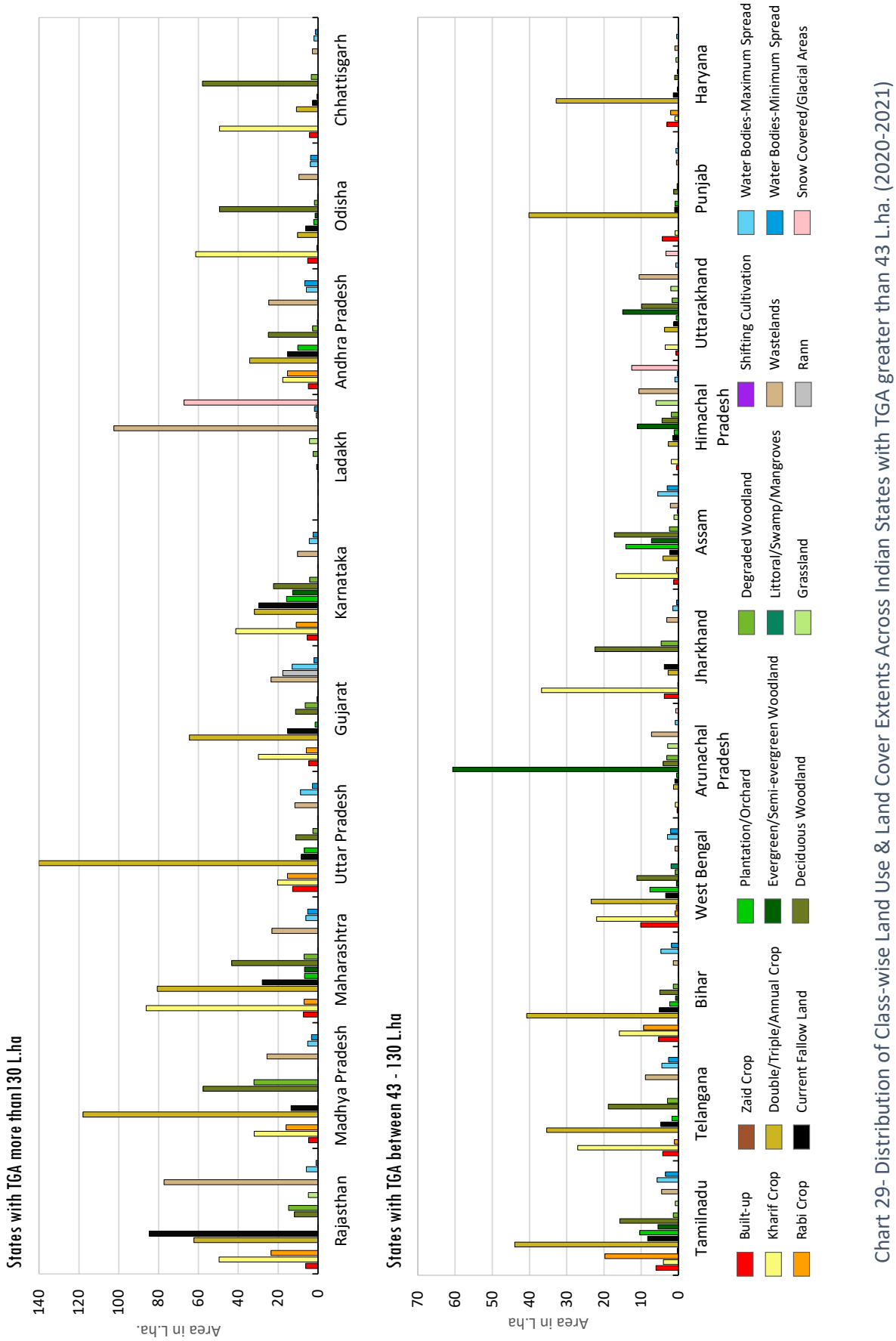

Chart 29- Distribution of Class-wise Land Use & Land Cover Extents Across Indian States with TGA greater than 43 L.ha. (2020-2021)

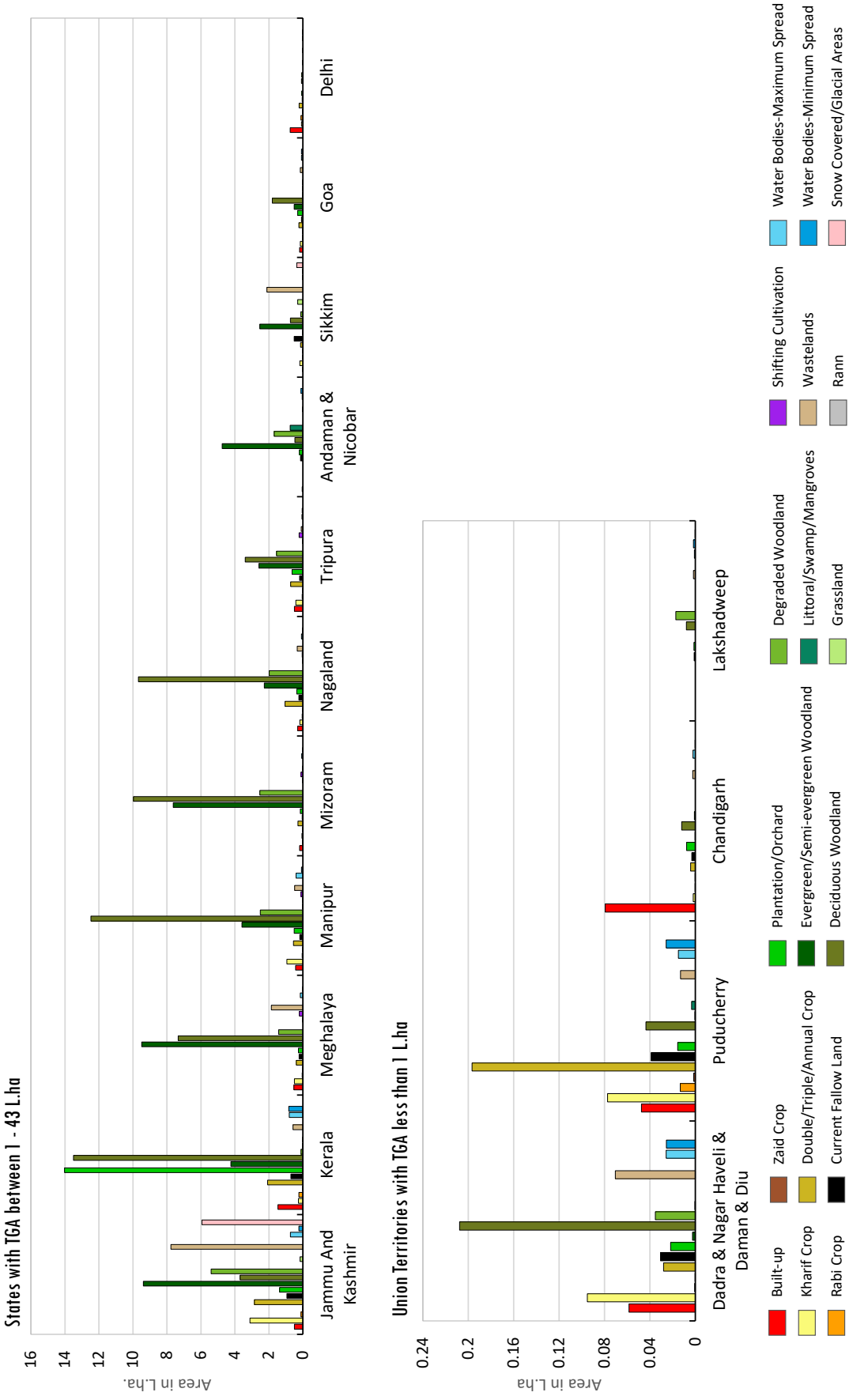

Chart 30- Distribution of Class-wise Land Use & Land Cover Extents Across Indian States with TGA less than 43 L.ha. (2020-2021)

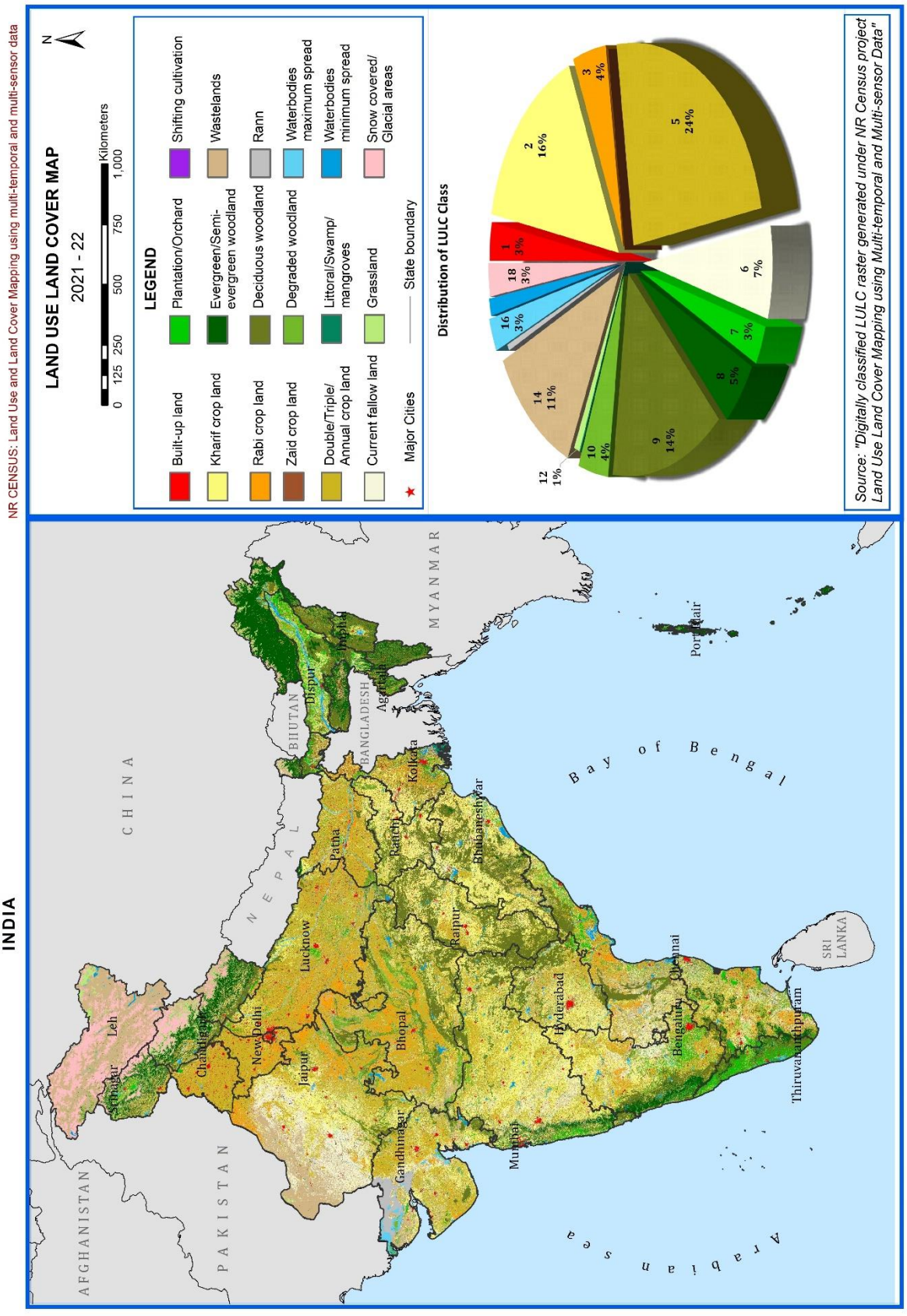

Figure 33- LULC map 2021-22

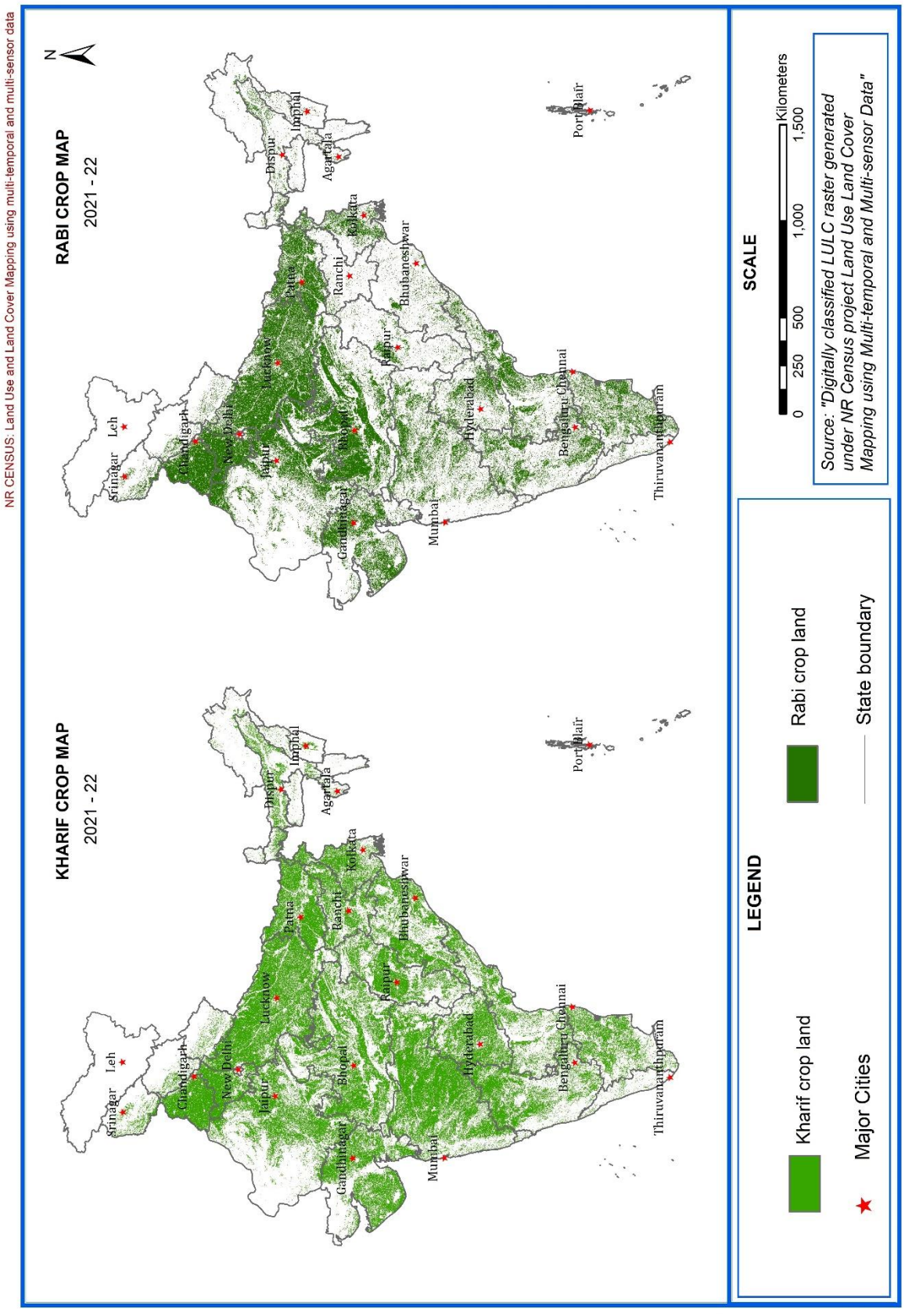

Figure 34- Crop map 2021-22

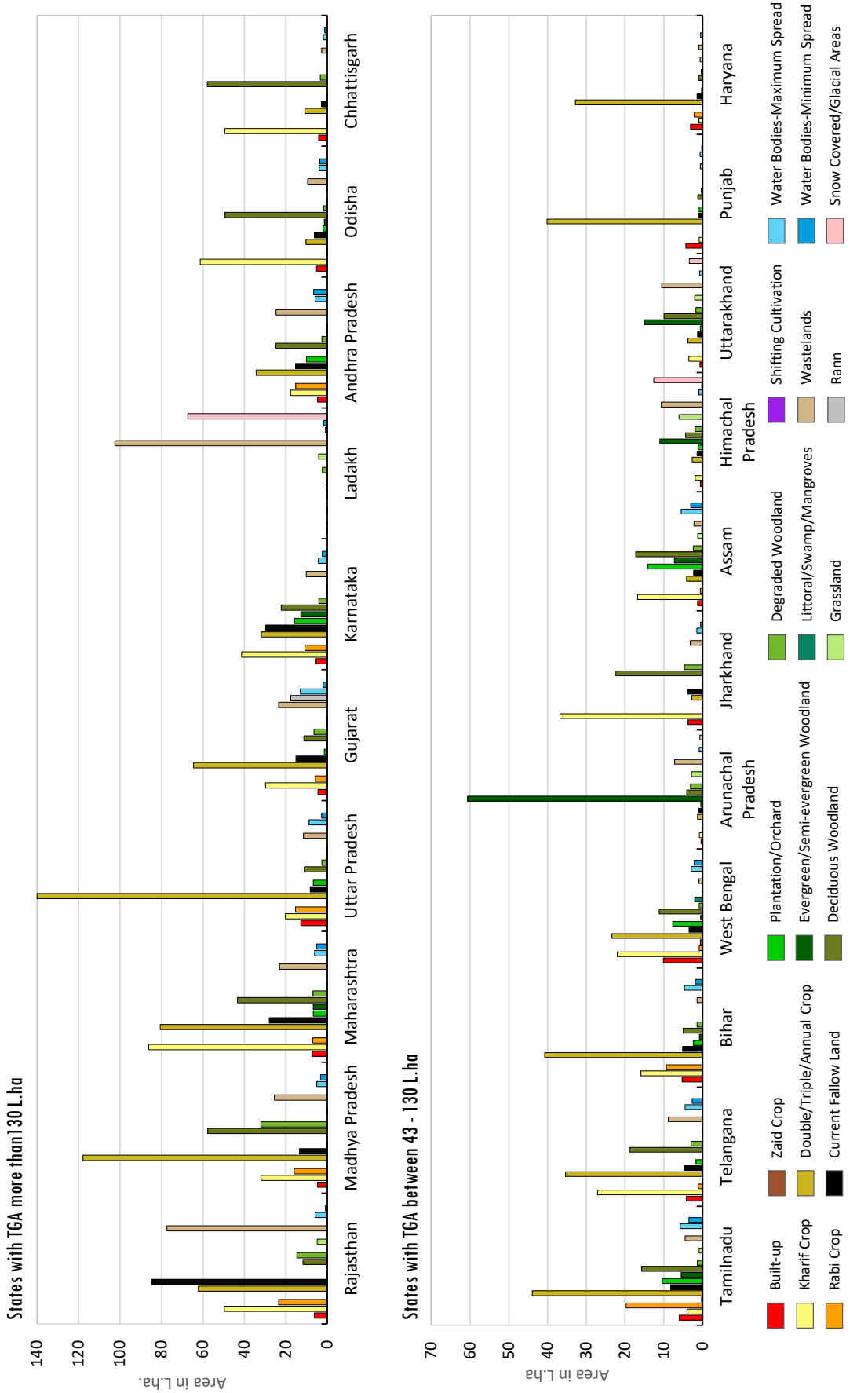

Chart 31- Distribution of Class-wise Land Use & Land Cover Extents Across Indian States with TGA greater than 43 L.ha. (2021-2022)

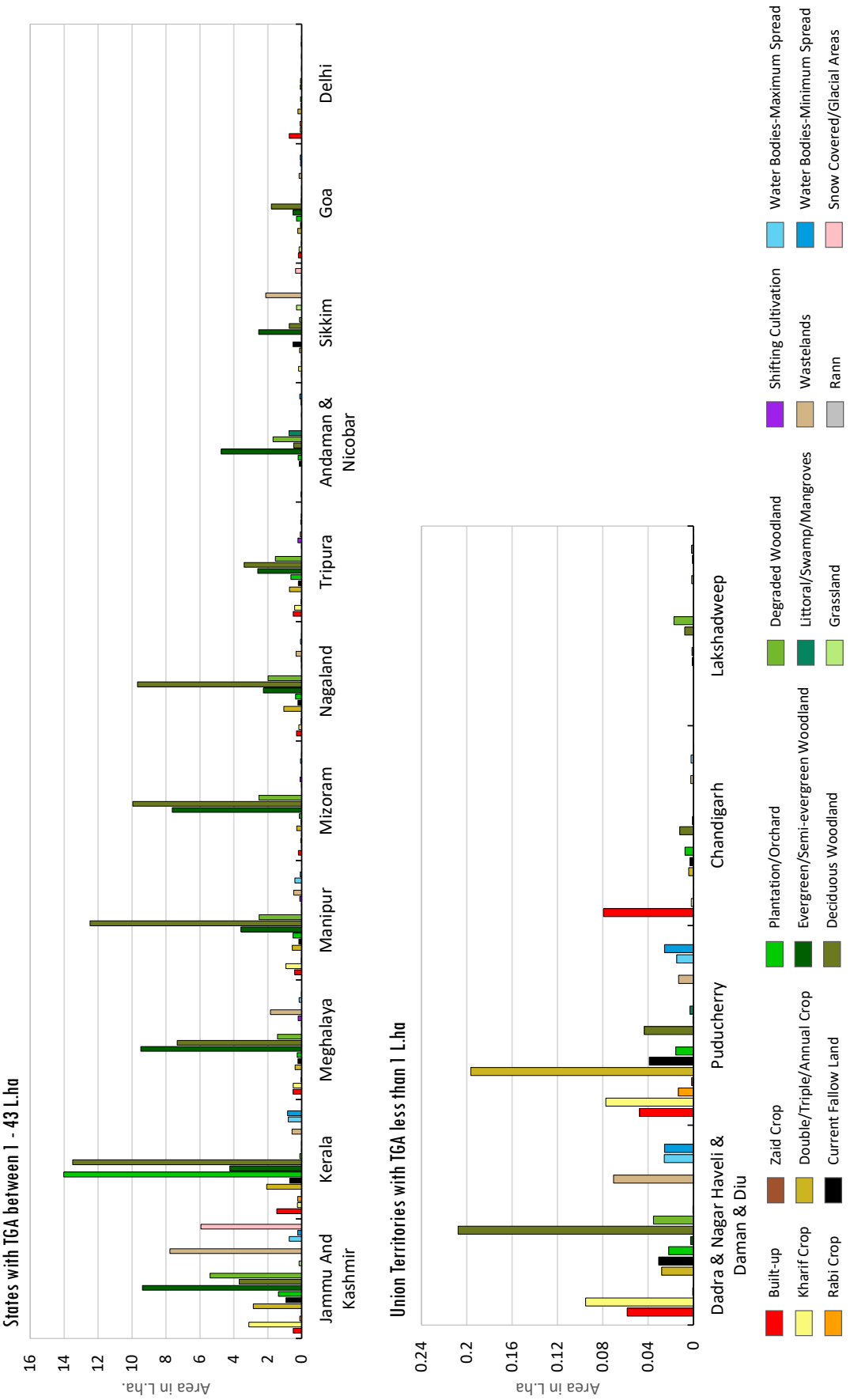

Chart 32- Distribution of Class-wise Land Use & Land Cover Extents Across Indian States with TGA less than 43 L.ha. (2021-2022)

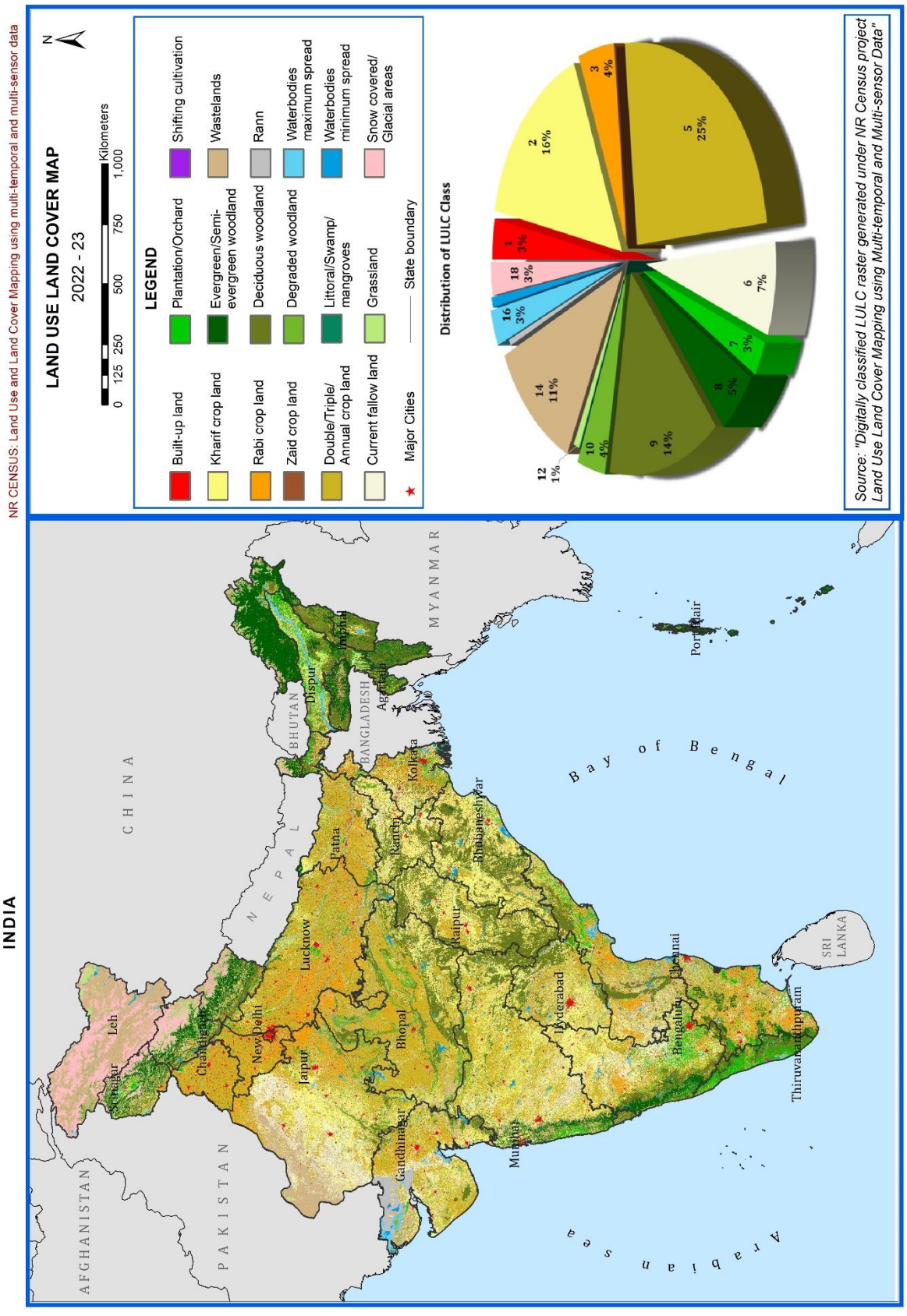

Figure 35- LULC map 2022-23

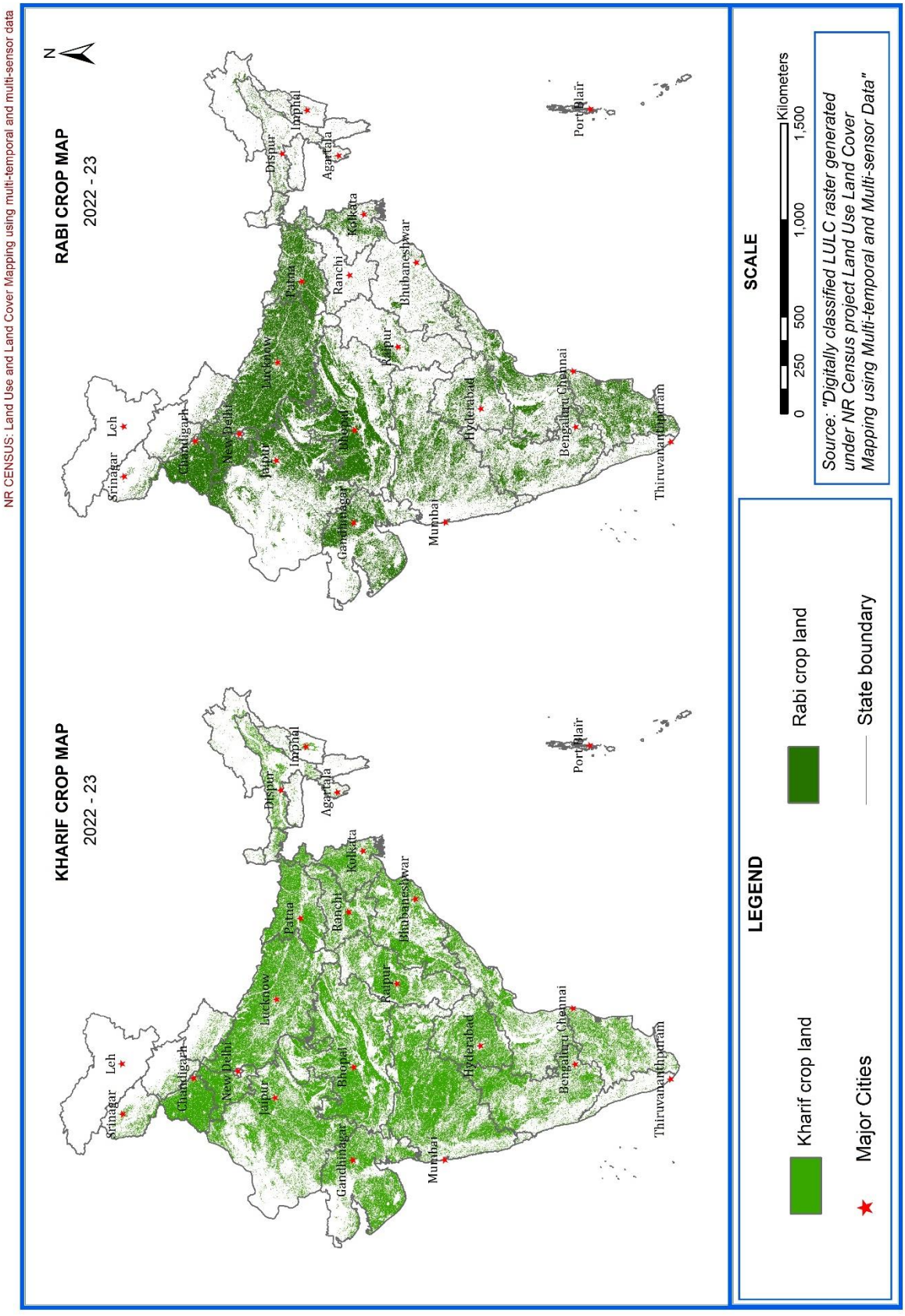

Figure 36- Crop map 2022-23

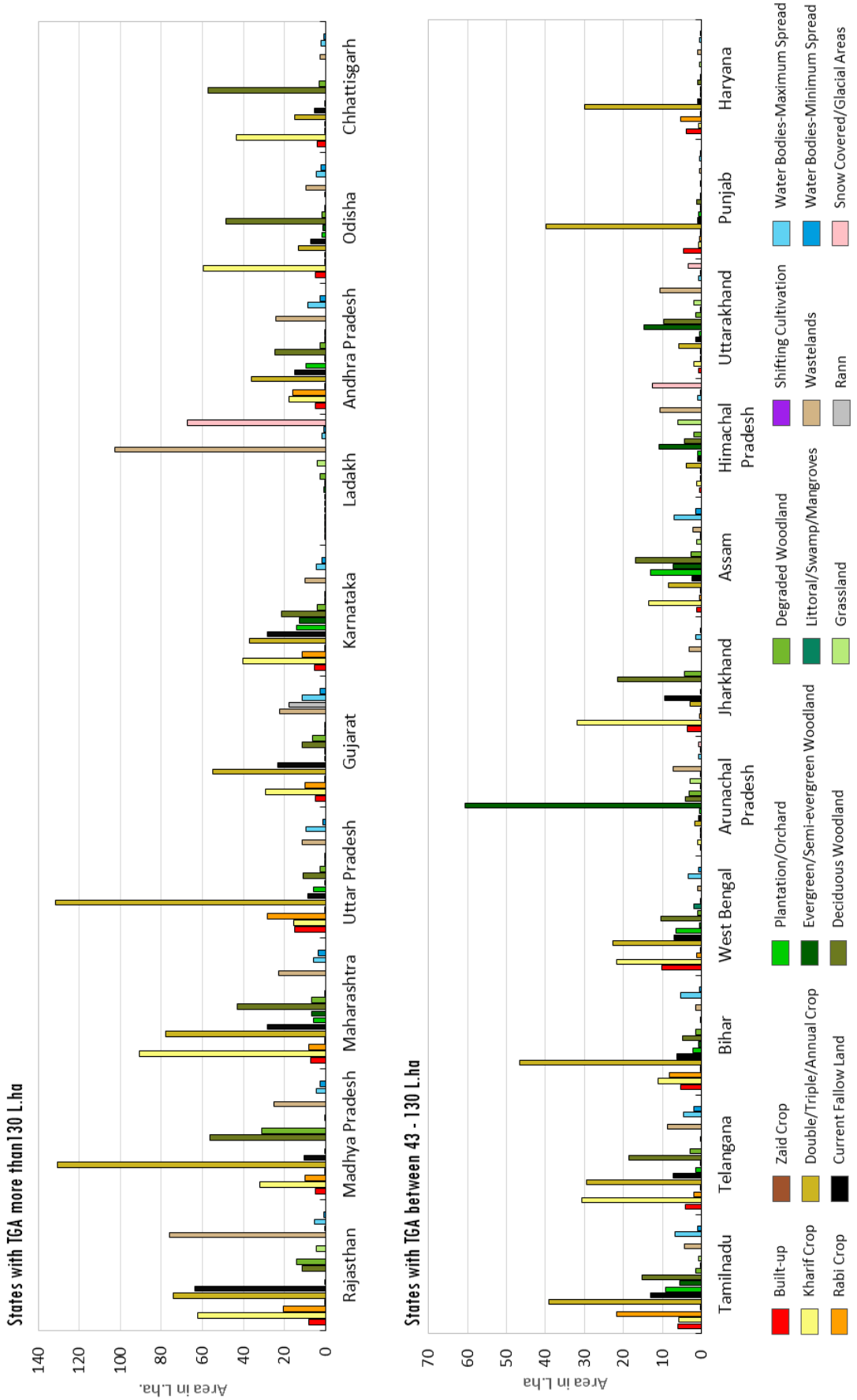

Chart 33- Distribution of Class-wise Land Use & Land Cover Extents Across Indian States with TGA greater than 43 L.ha. (2022-2023)

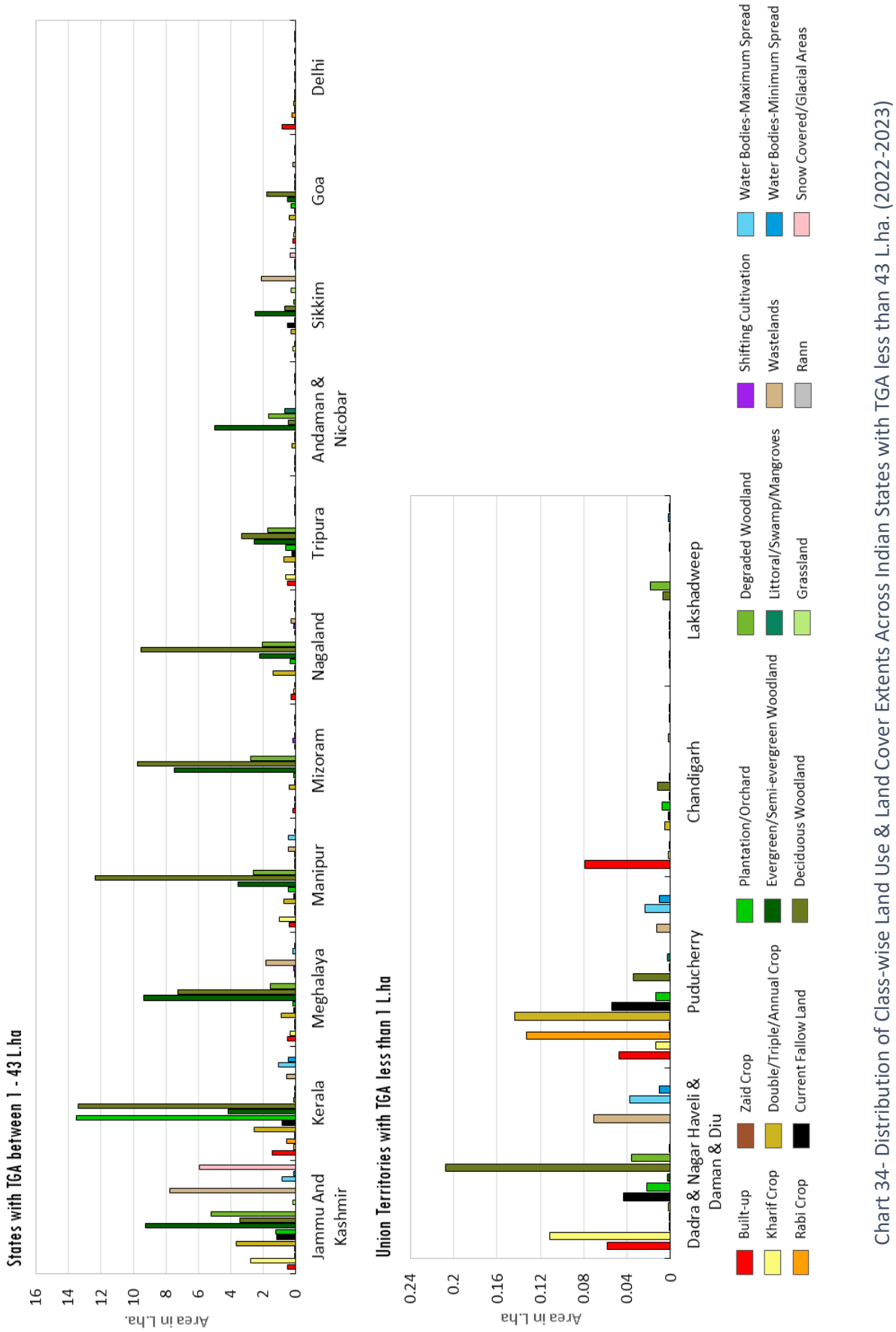

Chart 34- Distribution of Class-wise Land Use & Land Cover Extents Across Indian States with TGA less than 43 L.ha. (2022-2023)

5. Results and Analysis

5.1 Analytical Observations

Trends in Land Use Land cover categories were examined for all mapping period from 2005-2023 and the most important characteristics are addressed here. Three major land cover types namely Double/Triple/Annual crop (D/T/A crop), Built-up, and Current Fallow, which shows its significance in agricultural growth, asset expansion and uncultivated agricultural land respectively. The state-wise statistics of the above mentioned land cover types are illustrated in Fig.37, 40 & 41. Trends are analysed as histograms to understand the long term deviations. Trend analysis has also been performed for Shifting Cultivation with Woodland classes as shown in Fig.42.

5.2 Analysis of Built-up Land Trends

Built-up is a distinctive cover which represents the growth and economic worth, as the expansion in permanent asset and infrastructure indicating mainly towards a developing economy. Trends of built up classes for rapidly growing states (Fig.37) appear to be relatively constant with a marginal increase in the area over the period of time. Whereas Madhya Pradesh, Gujarat, Karnataka, West Bengal and Andhra Pradesh show distinct increase in this theme.

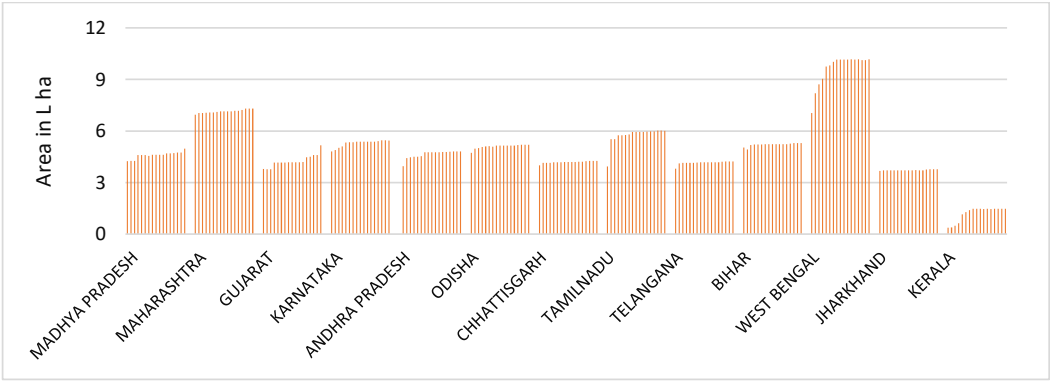

Figure 37- Long term trends of Built-up Land across states over annual mapping cycle

A comprehensive assessment of land cover patterns across India between the first (2005-06) and seventeenth (2022-23) cycles of the Annual Land Use and Land Cover (LULC) mapping reveals a consistent increase in built-up area, expanding approximately by 25 lakh hectares. This notable transformation underscores the rapid pace of urbanization and infrastructure development across the country during this period.

Specific land cover classes contributing to this built-up area expansion is shown in Fig.38. It points to the fact that about 35 percent of built up is added over 17 years (~2.4 percent increase each year) from mentioned covers. Wastelands, encompassing degraded and unproductive lands, contributed significantly to built-up area expansion by 12.3 percent. Notably, a substantial percentage of built-up area expansion originated from agricultural land covers, which includes 6.3 percent of double/triple/ annual crop, 5.3 percent of kharif crop, 3.1 percent of rabi crop, 2.9 percent of plantation and 5.8 percent of fallow land.

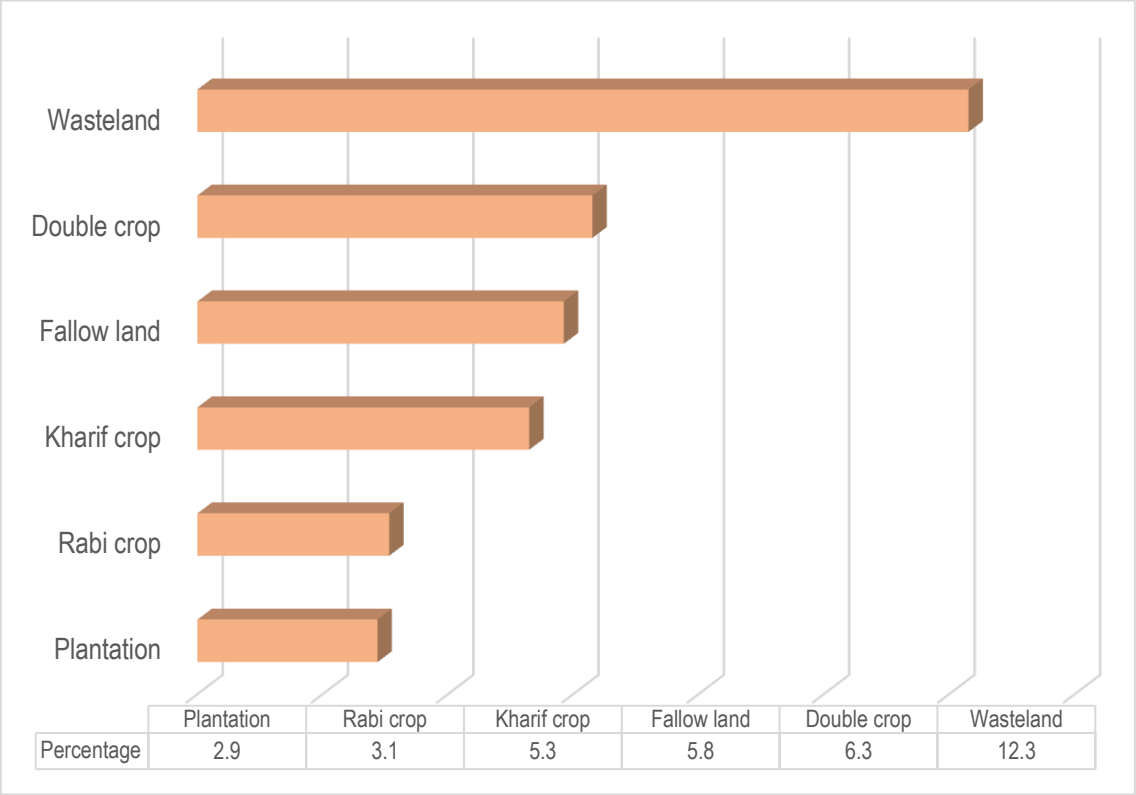

Figure 38- Contribution of Different Land Covers to Built-up extents between First (2005-06) and Seventeenth (2022-23) Cycles of Annual LULC Mapping

5.3 Analysis of Double/Triple/Annual Crop Trends

Analysis reveals fairly strong relation between Double/Triple/Annual crops and Current fallow land, when observed at national level. Perspectives from the trends (Fig.39)

reveal a consistent overall increase in the double/triple/annual cropping across the annual mapping periods. This observed increase coincides with a concurrent decrease in the extent of fallow land cover during these periods. Cropping which covered 710.8 L ha in 2005-06 period has shown an expansion to an area of about 961.3 L ha in 2022-23. Fallow extent was 447.6, which got reduced to 245.3 L ha in 2022-23.

The cumulative effect observed can be attributed to increased or improved availability of farm inputs such as improved irrigation facilities, market demand, groundwater use, enhanced farm nutrition through subsidized fertilisers etc. This trend is highly desirable providing insights into the economic development of agricultural production.

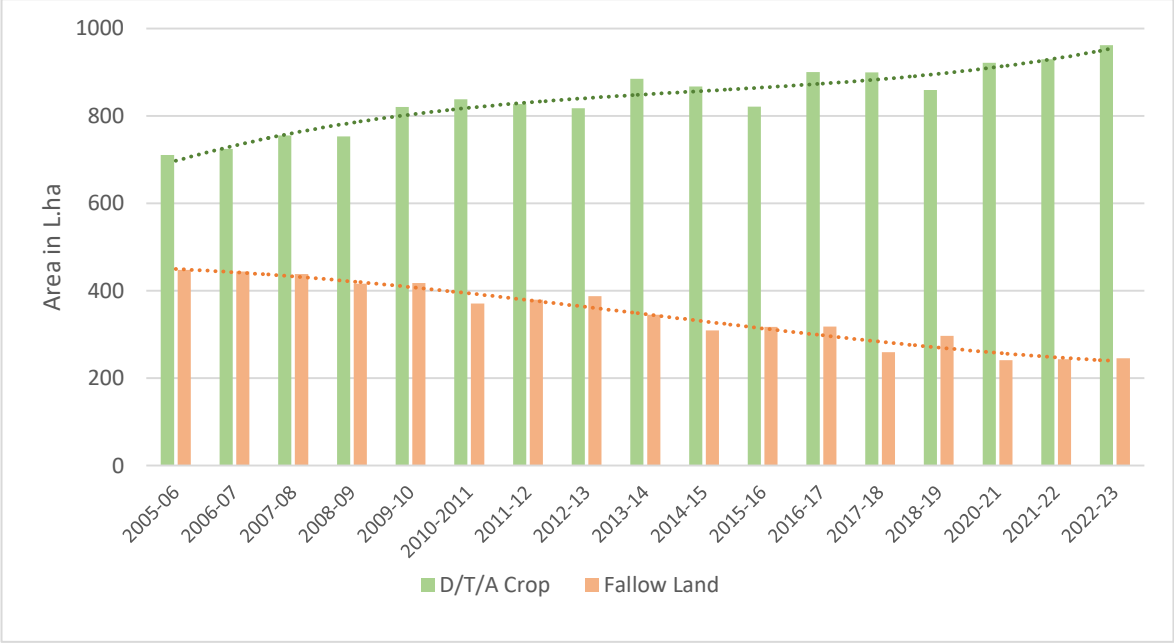

Figure 39- Long term Trends of Double/Triple/Annual crop and Fallow Land over Annual mapping cycles at national level

5.4 State level Trends for Double/Triple/Annual Crop

State level trends were derived to assess the variation in the cropping area over the study period. Madhya Pradesh, Uttar Pradesh and Bihar clearly indicate consistently increasing trend of D/T/A crop area, while current fallow for these states has shown commensurate decline (Fig. 40 and 41). Relation between these entities show a typical declining rate (Fig 42) indicating a gradual reduction of fallow with respect to cropped

area. Whenever these states witnessed higher cropping areas over the study period, area under fallow land has shown declining trend.

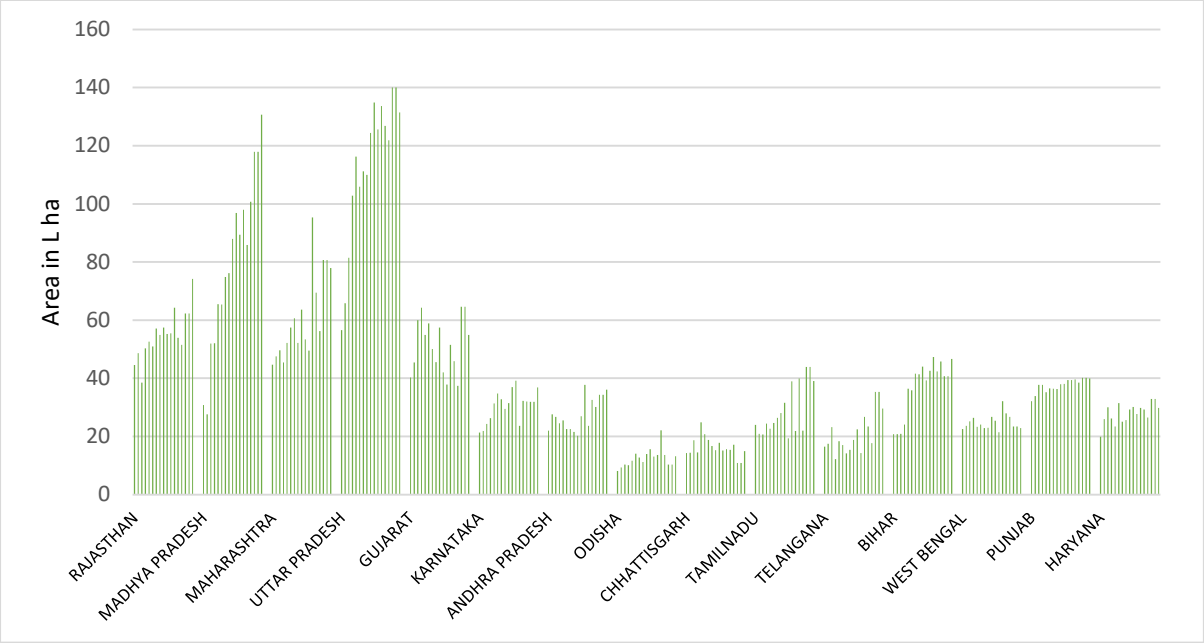

Figure 40- Long term trends of Double/Triple/Annual crop land across states over annual mapping cycle

Rajasthan and Maharashtra indicated slightly differing trends (Fig 40 and 41) wherein, increase in cropped area was marked by intermittent decline, along with the mixed response of decrease in current fallow areas. Rajasthan showed initial decrease of area under current fallow, followed by an increase in later years, while in Maharashtra it increased in first four years followed by a decrease.

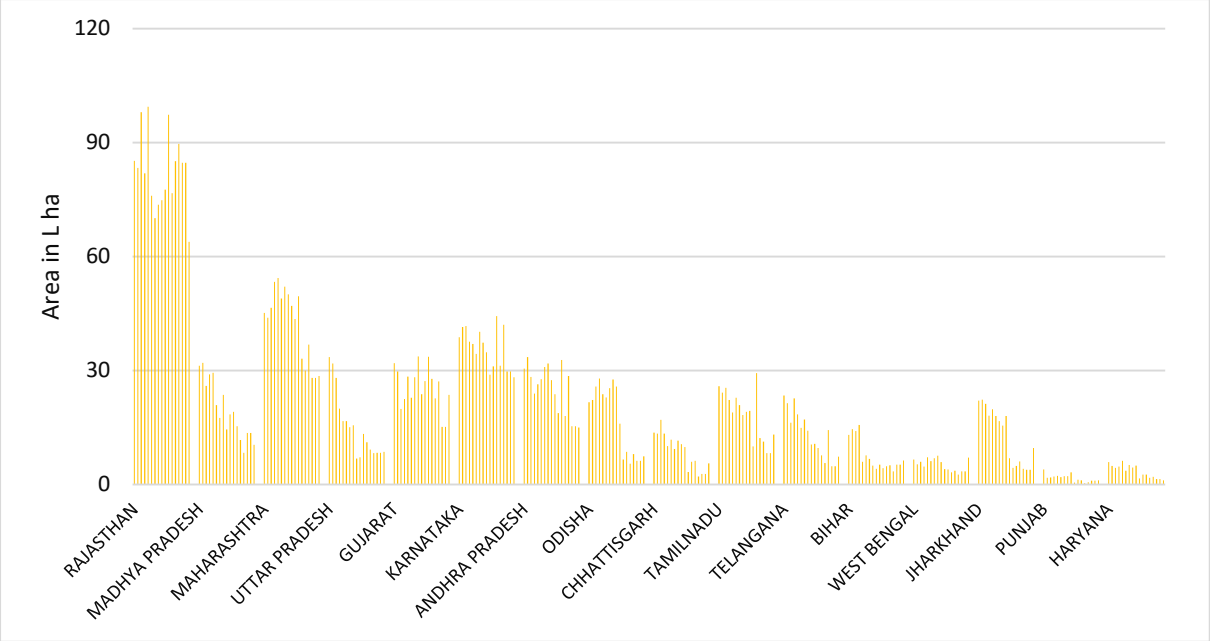

Figure 41- Long term trends of Current Fallow Land across states over annual mapping cycle

5.5 Trend Analysis between Shifting Cultivation and Woodland

Shifting cultivation also known as *Jhum cultivation* is an example of primitive way of farming most commonly practised in hilly forested tracts of Eastern and North Eastern region of the country by tribal communities, having traditions of slash and burn agriculture. Possibly due to the high demand for food production, there is an increase in area under shifting cultivation is observed from last several years. As depicted in the illustration (Fig.42) presence of larger spatial extents of shifting cultivation is associated with lesser amount of woodland over the mapping cycles studied (each data point in the graph). Higher strength of relationship (R^2=0.684) clearly brings out national level trend over long term period.

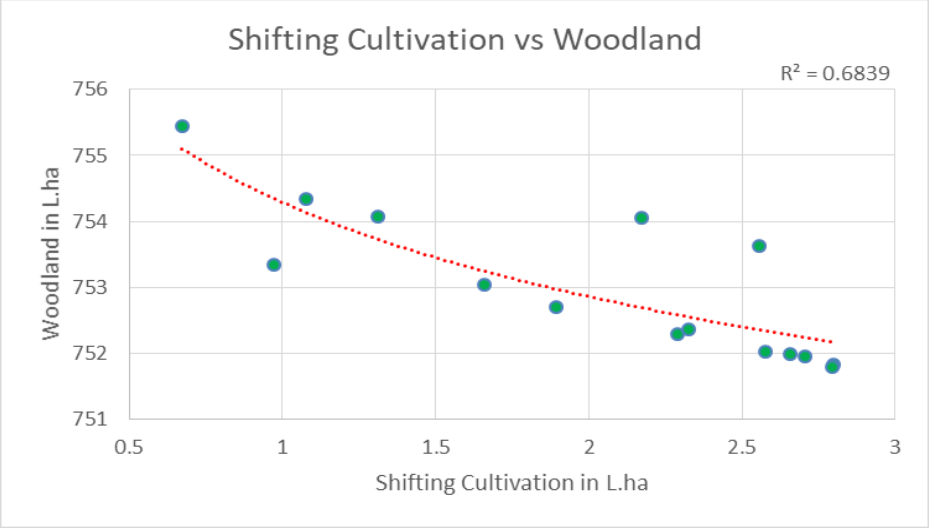

Figure 42- Relationship of Shifting Cultivation with Woodland cover extents over Annual mapping cycles (Each point represents a mapping cycle)

Conclusion

Satellite Remote Sensing techniques allow generating reliable and long term information of Land Use and Land Cover which in turn help to monitor their changes periodically. However, use of legacy spatial database and ancillary data help in improving the results derived from satellite data interpretation. Outcomes of the project over a span of 17 mapping cycles has revealed interesting and valuable insights to Indian land cover dynamics which will be of great utility to wide range of stakeholders. The Land use and Land Cover data presented in this atlas are very useful for planning, monitoring and development purposes by government planning departments, institutions involved research activities as well as by NGOs, academics, etc.

Following are some of the major useful activities:

- Formulation of development programme in the Ministries and Departments like Agriculture, Rural Development, Environment and Forest, Water Resources and others.
- Monitoring of dynamic land covers like surface water, forest, wastelands etc.

- Climate related impact studies can be done using this mid resolution annual LULC data.
- To quantify the type and amount of land available for essential societal needs such as food, water, energy, etc.

Trends explored and understood in this study, point towards desirable patterns of increase in the area under crop in the form of double/triple/annual crop and conversion of wastelands and current fallow to more productive and preferred land management practices. Constraints contributing to the underutilization or incapacity to fully exploit land use potential (fallow/wasteland prevalence), in earlier years seem to have eased out. Relation of woodland with Shifting Cultivation also showed higher level of cultivation with reduced woodland cover, which indicates the potential of restoration measures that may steer the reduction of unsustainable practice of slash and burn farming.

In the context of fast altering natural resource situations, it is critical to understand the changes occurring on earth surface so as to analyse them and develop decision support alternatives to attain sustainable growth. Support to such quantification provides, modelling of land cover changes is significant and can provide critical backup for all international negotiation related to climate change and resource balancing needs. Continuous focus maintained by ISRO-NNRMS initiative of this nature, has resulted in NRSC taking further responsibility of providing multisource data based LULC preparation catering to the national needs. This also attempts to fulfil the government policy requirements. Analytics brought out from such institutionalised efforts would help in manoeuvring development trajectories in a more scientific and transparent manner.

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Annexure I

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Technical Guidance

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Following members participated in this Long Term Study for various types of activities/teams mentioned here

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b	Geo-Database Creation & Organisation			f	FTP Server Support
c	Data Processing and Dissemination			g	Report Preparation
d	Pre Processing, Classification, Mapping			h	Web Dissemination

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25	Hariesh P	54	Ramana K V	83	Trivedi Shivam
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Annexure II

S. No	LULC Class	Description
1	Built-up land	Residential areas, industries, airport and other impermeable surfaces generated by anthropogenic activity.
2	Kharif crop land	Seasonal Crop land with crops grown during June to November period of agricultural calendar year.
3	Rabi crop land	Seasonal Crop land with crops grown during November to April period of agricultural calendar year.
4	Zaid Crop land	Seasonal Crop land with crops grown during April to June period of agricultural calendar year.
5	Double/Triple/annual crop land	Land with crops grown in more than one season specified above. This will also include annual crops.
6	Current Fallow land	Agricultural area in which crop is not grown during any part of the season of agricultural calendar year.
7	Plantation / Orchard	Trees which are artificially planted.
8	Evergreen / Semi-evergreen Woodland	This category comprises of trees (>2m tall), which are predominantly remain green throughout the year. It includes both coniferous and tropical broadleaved evergreen species. Semi- evergreen is a woodland type that includes a combination of evergreen and deciduous species with the former dominating the canopy cover.
9	Deciduous Woodland	These are the woodland types that are predominantly composed of tree (>2m tall) species, which shed their leaves once a year. It may also include tree clad area with tree cover lying outside the notified forest boundary areas that are herbaceous with a woody appearance
10	Degraded Woodland	Land covered with tree species (more than 2m tall) which are Evergreen / Deciduous in nature with relatively decreased density of trees.
11	Littoral/Swamp/Mangroves	Areas with seasonal or permanent water ponding (with or without vegetation) excluding the water bodies. These include ox-bow lakes, tidal flat/mud flat, mangrove, salt marsh/marsh vegetation and other hydrophytic vegetation.
12	Grassland Land	Areas with seasonal or perennial grasses occur naturally.
13	Shifting cultivation	These are the areas where woodlands are cleared and used for cultivation.
14	Wastelands	These are barren lands with nil or little vegetation cover and includes areas like rocky areas, scrub lands, mining dumps, gullied lands, sand dunes, etc.
15	Rann	These are the areas with very high concentrations of salts usually sourced from sea and occur near the sea coasts.
16	Water Bodies – Maximum spread	This represents the maximum water spread in a water body like lakes, tanks, reservoirs, rivers, etc.
17	Water Bodies – Minimum spread	This represents the least water spread in a water body like lakes, tanks, reservoirs, rivers, etc.
18	Snow covered / Glacial areas	Land under snow cover / ice, mostly permanent.

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