Vegetation Degradation in Non-Arable Areas of India

Indian Council of Agricultural Research
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FOREWORD

India's non-arable land constitutes a critical ecological resource, supporting biodiversity, hydrological regulation, carbon sequestration, and rural livelihoods. However, many of these landscapes are under increasing pressure due to development demands, encroachment, recurrent droughts, and land-use transitions. Effective monitoring of vegetation degradation in such heterogeneous and often inaccessible terrains requires the integration of modern earth observation technologies with scientific field verification.

This technical report provides a comprehensive, scalable, and scientifically rigorous framework for assessing vegetation degradation across India's agro-ecological zones. By leveraging multi- temporal remote sensing data and state-of-the-art geospatial analytics, the study offers insights into the degradation hotspots, trends, and spatial variability. The validation protocols further strengthen the reliability of the outputs, enhancing their utility for national and state-level planning.

The knowledge presented in this report on vegetation degradation aligns with India's commitments to the UN Convention to Combat Desertification, Land Degradation Neutrality, and climate-resilient land management. It will undoubtedly contribute to informed decision making, targeted interventions, and long-term ecological restoration strategies.

I commend the authors for their meticulous work and trust that this report will guide stakeholders towards sustainable stewardship of India's non-arable landscapes.

(Dr Mangi Lal Jat)
Secretary, Department of Agricultural Research and Education (DARE)
& Director General, Indian Council of Agricultural Research (ICAR)

March 17, 2026
New Delhi

MESSAGE

Vegetation degradation on non-arable lands poses a significant threat to ecological stability, watershed health, and sustainable land management across India's diverse agro-ecological regions. With rapid land-use changes, increasing anthropogenic pressures, and climate-induced stresses, timely and accurate assessment of vegetation condition has become essential for informed planning, policy formulation, and restoration efforts.

This technical report presents a systematic approach for identifying and mapping of vegetation degradation, using multi-temporal remote sensing datasets and advanced geospatial tools. The methodology integrates satellite-based indicators, spatial modelling techniques, and rigorous validation to produce reliable, region-specific insights into degradation patterns. By harmonizing high-resolution datasets with validations, the report provides a robust framework applicable to various non-arable landscapes, including uplands, wastelands, forest margins, and degraded commons.

The outcomes of this work are expected to support national initiatives on land restoration, climate resilience, natural resource management, and sustainable development. Hope this document serves as a valuable reference for researchers, technical agencies, policy planners, and development practitioners working toward environmental conservation and landscape restoration in India.

I appreciate the authors and the scientific team at ICAR–NBSS&LUP for producing this comprehensive National appraisal on vegetation degradation in India. The scientific support and inputs provided by the Director, ICAR-NBSS&LUP, Members of the Committee on Vegetation Degradation Mapping, ADG (S&WM) and Principal Scientists of the NRM Division, ICAR, New Delhi are duly acknowledged. The study's insights will support policymakers, planners, researchers, and field practitioners in advancing Land Degradation Neutrality, climate-resilient agriculture, and sustainable natural resource stewardship. These findings strengthen our collective mission of promoting science-led solutions for the conservation of natural resources. It will also serve as an essential reference for all those engaged in the vital work of sustainable natural resource management.

(Dr Amaresh Kumar Nayak)
Deputy Director General (Natural Resource Management),
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March 18, 2026
New Delhi

PREFACE

The degradation of non-arable lands has emerged as a significant component of India's overall land degradation status, further it adversely contributes to watershed deterioration, reduced ecological stability, and increased vulnerability to climate change. Though these landscapes are not under crop cultivation, but they perform essential ecological functions, including carbon sequestration, soil and water conservation, biodiversity support, and acting as buffer zones for agricultural and forest ecosystems. Vegetation degradation commonly manifests in the form of deforestation, forest blanks, shifting cultivation, overgrazing, and the degradation of pasturelands and scrublands. It serves as a key indicator of land degradation processes and severely affects biodiversity and ecosystem services. The present report represents a first-order approximation of vegetation degradation in India's non-arable landscapes, developed primarily using remote sensing techniques and limited field observations. This publication is expected to serve as a decision-support tool for policymakers, planners, and extension agencies in designing targeted interventions for vegetation degradation management and location-specific input recommendations. The findings of the study also serve as an essential reference for all those engaged in the vital work of sustainable natural resource management.

The authors gratefully acknowledge the valuable guidance and constant support from Dr A.K. Nayak, Deputy Director General (Natural Resource Management), ICAR, New Delhi. The valuable coordination and support from Dr A. Velmurugan, ADG (S&WM), ICAR, New Delhi, Dr Adlul Islam, Principal Scientist and Dr R.S. Yadav, Principal Scientist of the NRM Division, ICAR, New Delhi are sincerely acknowledged. The insights provided by the Committee Members of Vegetation Degradation Mapping are also acknowledged.

Authors

CONTENTS

1. Rationale for Vegetation Degradation Assessment in India's Non-Arable Lands

Vegetation degradation refers to the temporary or permanent decline in vegetation cover, structure, productivity, species composition, or density. The degradation of non-arable lands has emerged as a significant component of India's overall land degradation status, contributing to watershed deterioration, reduced ecological stability, and increased vulnerability to climate change. Although these landscapes are not typically used for crop cultivation, they perform essential ecological functions, including carbon sequestration, soil and water conservation, biodiversity support, and acting as buffer zones for agricultural and forest ecosystems. Vegetation degradation commonly manifests in the form of deforestation, forest blanks, shifting cultivation, overgrazing, and the degradation of pasturelands and scrublands. It serves as a key indicator of land degradation processes and can severely affect biodiversity, ecosystem services, and agricultural productivity.

Earth observation datasets, particularly from platforms such as Landsat, Sentinel, the Moderate Resolution Imaging Spectroradiometer (MODIS), Indian Remote Sensing (IRS) satellites, and other high-resolution sensors, enable continuous monitoring of vegetation health, cover, and structural dynamics. Vegetation indices, spectral reflectance patterns, and multi-season composites facilitate detailed characterization of degradation processes. Among these, remote sensing–based vegetation indices such as the Normalized Difference Vegetation Index (NDVI) have become reliable and repeatable tools for monitoring and evaluating temporal changes in vegetation cover (Ezaidi et al., 2022; Jacquin et al., 2010).

However, most previous NDVI-based analyses of vegetation degradation across India and other regions of the world have relied on coarse-resolution datasets, such as the Advanced Very High-Resolution Radiometer (AVHRR) and MODIS (Kumar et al., 2022). Several analytical approaches have been widely applied to detect long-term vegetation

changes, including Seasonal and Trend decomposition using Loess (STL) (Jacquin et al., 2010), linear regression (Eckert et al., 2015), the Mann–Kendall trend test coupled with the Theil–Sen slope estimator (Adenle et al., 2020; Delgado-Moreno and Gao, 2022), and Residual Trend Analysis (RESTREND) (Gichenje and Godinho, 2018). Compared with parametric linear regression, the Theil–Sen slope is a non-parametric statistical approach that is more robust to outliers and missing observations (Adenle et al., 2020).

Despite the availability of these technologies, India currently lacks a standardized, technically validated, and field-corroborated methodology specifically designed to monitor vegetation degradation in non-arable lands. In the present study, vegetation degradation was assessed across diverse non-arable landscapes, including scrublands, grasslands, degraded forests, uplands, ravines, steep slopes, wastelands, coastal and inland wetlands, mangroves, mine spoils, quarry and industrial dump areas, saline and sodic tracts, sandy deserts, rocky outcrops, and other ecologically fragile regions. The assessment was carried out using Landsat-8 satellite imagery at a 30 m spatial resolution in combination with the Theil–Sen slope method.

This technical report addresses this critical gap by developing an integrated, scalable, and repeatable methodology for identifying, mapping, and monitoring vegetation degradation across India's non-arable lands. The study leverages multi-temporal Landsat-8 imagery, advanced geospatial analytics, and systematic validation to generate robust and reliable results. Furthermore, the report provides a scientific foundation for assessing the current status, spatial distribution, and severity of vegetation degradation in India, thereby supporting long-term national commitments to ecological restoration and sustainable land management.

2. Datasets Used

For the purpose of vegetation degradation assessment, multi-temporal Landsat-8 surface reflectance data, obtained from the Google Earth Engine (GEE) platform, were used to analyze vegetation dynamics over the period 2014 to 2024.

Imagery acquired between January and May of each year was specifically selected to minimize seasonal variability, reduce cloud contamination, and ensure consistent phenological conditions across years. The dataset, with a spatial resolution of 30 m, provided the required spectral bands, particularly the red and near-infrared wavelengths, for robust computation of the Normalized Difference Vegetation Index (NDVI).

In addition, the European Space Agency (ESA) WorldCover 2020 Land Use/ Land Cover (LULC) dataset at 10 m spatial resolution was used to generate a precise cropland mask, enabling the exclusion of agricultural areas from the degradation assessment. Together, these datasets provided a reliable and spatially consistent foundation for analyzing long-term vegetation trends and degradation patterns across the study region (Table 1).

Table 1. Various datasets used in the study

Data Product	Type of Data	Units / Format	Data Period & Update	Temporal Resolution	Spatial Resolution / Scale	Source
ESA LULC 10 m	Land Use / Land Cover (Classified Raster)	Categorical Classes	Annual assessments (e.g., 2020, 2021)	Annual	10 m	European Space Agency (ESA) WorldCover
Vegetation Map of India (FSI)	Forest Cover Map (Primarily Vector)	Density Classes (Vector Polygons)	Biennial Cycles (e.g., 2019, 2021)	Biennial	1:50,000 scale (LISS-III ~23.5 m)	Forest Survey of India (FSI), MoEF&CC
Google Maps (Base Imagery)	Integrated Mapping Platform	Geographic Coordinates, Visual Tiles	Continuous composite (vintage varies by location)	Irregular (High-priority areas updated frequently)	Variable (Scale-dependent). < 0.5 m to > 15 m.	Google (Aggregates Maxar, Airbus, CNES, Landsat, etc.)
NDVI	Continuous	Unitless raster	Jan to May 2014 to 2024	Annual	30 m	Landsat-8

3. Methodology

Median Landsat-8 Level-2 surface reflectance data were acquired and processed using the Google Earth Engine (GEE). To minimize seasonal variability and cloud contamination, imagery acquired between January and May of each year from 2014 to 2024 was selected. All datasets were standardized to a spatial resolution of 30 m to ensure consistency in analysis. The Normalized Difference Vegetation Index (NDVI) was computed for each image using the near-infrared (NIR) and red spectral bands according to the following formula:

$$NDVI = \frac{NIR - Red}{NIR + Red}$$

GEE was subsequently used to efficiently process and generate the NDVI time series for the defined study area.

Agricultural croplands were masked to isolate vegetation degradation in non-agricultural landscapes, including forests, shrublands, and grasslands. For this purpose, the European Space Agency (ESA) WorldCover Land Use/Land Cover (LULC) dataset, derived from Sentinel-1 and Sentinel-2 imagery at a spatial resolution of 10 m, was employed to delineate cropland areas.

The Theil–Sen slope estimator was applied to calculate the pixel-wise rate of change in NDVI over the study period. In addition, the Mann–Kendall trend test was

used to evaluate the statistical significance of observed NDVI trends and determine whether a monotonic increasing or decreasing trend existed at each pixel over time. Negative slope values indicated vegetation degradation, whereas positive slope values represented vegetation improvement or aggradation.

Pixels exhibiting statistically significant negative Theil–Sen slope values ($p < 0.05$) were classified into five vegetation degradation severity categories: very severe, severe, moderate, low, and very low. Class thresholds were determined using the Fisher–Jenks optimization algorithm applied to the distribution of statistically significant slope magnitudes. Subsequently, areas occupied by water bodies, snow cover, and human settlements were masked from the final vegetation degradation layer.

The vegetation degradation map was validated using a dual approach involving field observations and high-resolution historical satellite imagery available through Google Earth. The overall methodology adopted for vegetation degradation mapping across India's non-arable landscapes is illustrated in Figure 1.

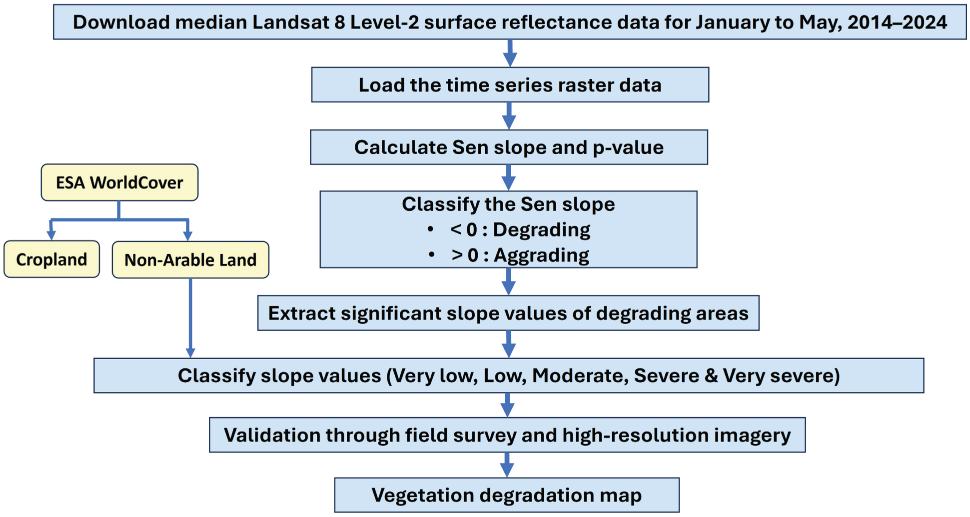

Fig. 1: Overall methodology followed in vegetation degradation mapping in India

4. Results and Analysis

The analysis of multi-temporal remote sensing data (2014 to 2024) revealed that non-arable lands across India exhibited diverse vegetation patterns shaped by regional climate, terrain, and land use pressures.

- About 1.93 Mha area is affected by various categories of vegetation degradation in India
- Around 39,310 ha is categorized under very severe vegetation degradation in India, out of which Arunachal Pradesh accounting for 12,011 ha

The assessment of vegetation condition indicated a clear spatial gradient, with some regions maintaining relatively stable vegetation cover, while others exhibited evident signs of degradation. Vegetation degradation was particularly pronounced in scrub-dominated landscapes, open forest fringes, ravine complexes, and rocky plateaus. In contrast, areas undergoing watershed development and afforestation programmes demonstrated gradual improvements in vegetation density and condition.

The observed degradation patterns appear to be driven by the combined influence of climatic variability, anthropogenic pressures, soil limitations, and topographic factors. Validation using high-resolution Google Earth imagery showed strong agreement between the remotely sensed vegetation degradation classes and ground conditions, with most mapped patterns accurately reflecting the actual landscape status.

The results further indicate that arid and semi-arid regions experienced widespread very severe and severe vegetation degradation across non-arable lands. Central India exhibited substantial degradation along forest fringes and mining-affected areas, whereas the north-eastern hill regions showed patchy but recurring vegetation loss, potentially associated with shifting cultivation cycles (Fig. 2). Overall, the analysis estimated that approximately 1.93 million hectares (Mha) of land in India fall under different categories of vegetation degradation. State-wise statistics of vegetation degradation across severity classes are presented in Table 2.

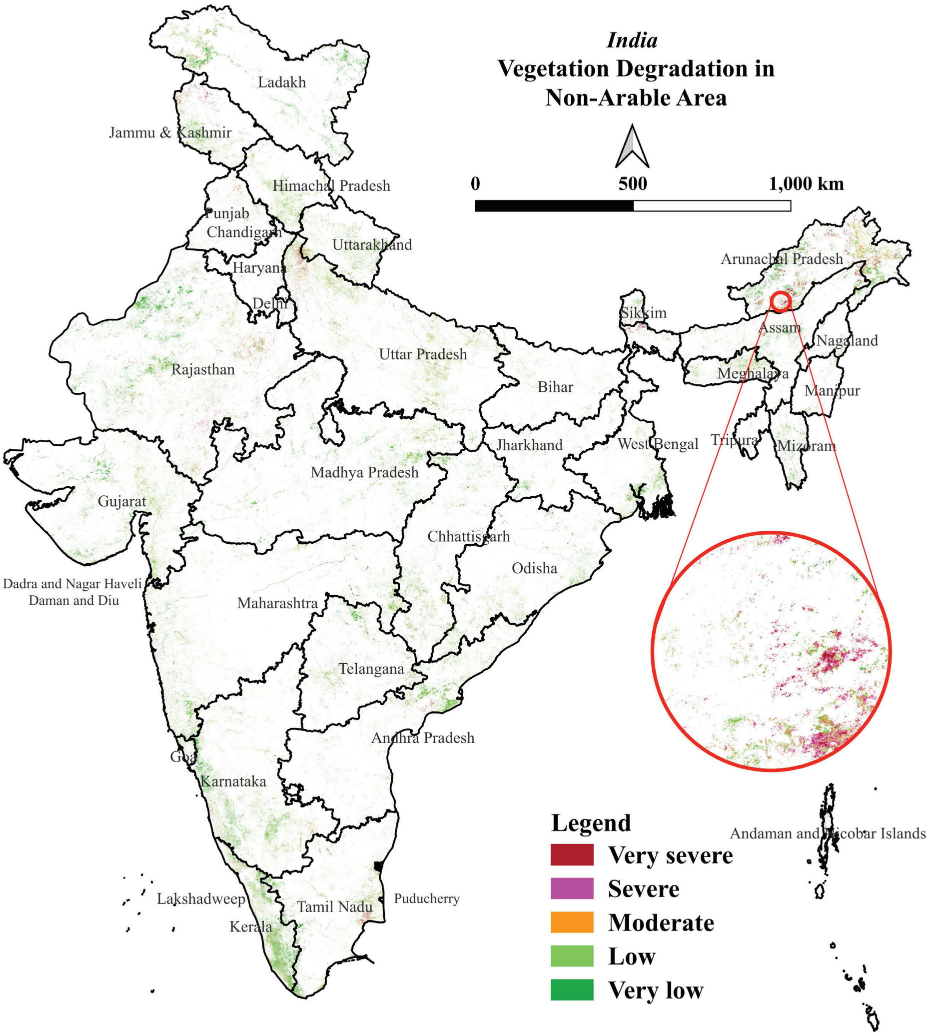

Fig. 2: Vegetation degradation in non-arable areas of India

Table 2. State-wise vegetation degradation statistics under various severity classes (Area in ha)

S. No.	State/UT	Vegetation degradation classes					
		Very severe	Severe	Moderate	Low	Very low	Total
1	Andaman & Nicobar Islands	0.0	0.0	36.1	2365.0	8241.1	10642.2
2	Andhra Pradesh	524.2	5843.3	18135.8	37507.4	27811.4	89822.1
3	Arunachal Pradesh	12011.1	31121.6	56897.7	53539.4	50714.5	204284.3
4	Assam	1683.9	5706.7	9449.2	14088.6	17028.5	47956.9
5	Bihar	706.6	2410.9	4638.4	6377.7	4531.8	18665.4
6	Chandigarh	0.1	0.5	0.5	0.2	0.0	1.3
7	Chhattisgarh	1234.8	6943.8	15293.6	24333.8	21193.1	68999.1
8	Delhi	54.2	127.5	181.0	154.6	81.6	598.9
9	DNHDD	0.0	0.1	1.1	3.2	5.4	9.8
10	Goa	139.1	547.3	1179.5	1799.2	1592.8	5257.9
11	Gujarat	114.0	4619.5	17233.1	37596.2	43419.0	102981.8
12	Haryana	912.2	2221.5	3212.2	2810.0	1469.4	10625.3
13	Himachal Pradesh	0.6	1669.9	7523.5	18152.7	6737.7	34084.4
14	Jammu & Kashmir	1896.0	4556.1	8332.9	14942.6	7957.0	37684.6
15	Jharkhand	494.6	1761.7	4260.4	8059.5	7709.6	22285.8
16	Karnataka	959.2	7416.8	23032.0	46086.8	53690.0	131184.8
17	Kerala	1368.7	7573.4	21882.7	39579.5	48664.6	119068.9
18	Ladakh	28.6	2156.6	9461.8	21984.9	48451.6	82083.5
19	Lakshadweep	0.0	4.0	93.2	389.2	414.4	900.8

20	Madhya Pradesh	707.8	5646.2	18127.9	36415.3	41446.4	102343.6
21	Maharashtra	1401.1	8928.6	24471.4	41755.1	37857.1	114413.3
22	Manipur	191.4	690.3	1263.5	1708.0	1414.1	5267.3
23	Meghalaya	545.6	2330.3	5394.9	8631.0	7328.7	24230.5
24	Mizoram	231.8	1231.0	3023.0	5519.3	8707.5	18712.6
25	Nagaland	329.0	760.4	1021.4	1383.5	1442.3	4936.6
26	Odisha	1111.3	5422.1	13096.9	20231.3	17761.5	57623.1
27	Puducherry	15.6	113.5	231.2	297.5	192.2	850.0
28	Punjab	861.0	3031.6	4620.2	4174.5	2037.2	14724.5
29	Rajasthan	4050.5	17556.3	35426.2	58259.8	99770.6	215063.4
30	Sikkim	0.5	1463.6	2001.6	2697.4	3454.9	9618.0
31	Tamil Nadu	2023.9	10287.5	20769.8	28920.1	28151.6	90152.9
32	Telangana	793.4	4789.6	11055.8	18239.0	18985.8	53863.6
33	Tripura	71.0	213.9	462.8	778.3	787.3	2313.3
34	Uttar Pradesh	2943.4	17896.5	37630.4	47203.1	24754.5	130427.9
35	Uttarakhand	1.4	2646.5	10346.9	18746.1	11385.5	43126.4
36	West Bengal	1903.1	3496.6	7677.4	17223.9	21222.5	51523.5
	Total Area	**39,309.8**	**171,185.5**	**397,466.1**	**641,953.5**	**676,413.1**	**1,926,328.0**

5. Summary

The validation of vegetation degradation classes was carried out by examining representative sites across all major degradation categories, namely *very severe, severe, moderate, low,* and *very low*, to ensure a comprehensive assessment of classification accuracy. Validation sites were strategically selected from diverse non-arable landscapes across India to capture regional variability in vegetation conditions and degradation patterns.

For each selected location, high-resolution Google Earth imagery was used as an independent reference dataset. These images enabled detailed visualization of land cover characteristics, vegetation density, bare soil exposure, scrub encroachment, ravine formations, and other surface indicators relevant to vegetation degradation assessment. A temporal comparison was conducted between the remotely sensed degradation outputs and corresponding Google Earth imagery from different years, facilitating the validation of vegetation decline, fragmentation patterns, and landscape transitions over time.

The assessment demonstrated strong agreement between the classified degradation categories and visual patterns observed in high-resolution imagery, suggesting good reliability of the remote sensing–based approach. However, although satellite-derived vegetation indices and trend analyses provide a robust and consistent framework for monitoring degradation across large spatial extents, they inherently involve interpretation challenges, particularly in heterogeneous and transitional landscapes where spectral signatures often overlap. Land cover types such as scrublands, degraded forests, rocky uplands, and shifting cultivation fallows may exhibit similar spectral responses, thereby complicating fine-scale discrimination.

These limitations highlight the need for systematic and extensive field validation across multiple ground control points to improve classification reliability and refine degradation categories in a region-specific context. Therefore, it is important to note that the present report represents a first-order approximation of vegetation degradation in India's non-arable landscapes, developed primarily using remote sensing techniques and limited field observations. The findings can be further refined and strengthened in subsequent phases through expanded field validation across diverse ecological and geographic settings.

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