February 2025

Scoping Study and Feasibility Assessment for the Development of Carbon Finance Project in Sikkim

teri

ReNew

Table of Contents

List of Figures

List of Tables

Introduction

Sikkim, with its unique topography and rich biodiversity, holds significant potential for the development of carbon finance projects. The state reports a recorded forest area (RFA) of 5,841 sq. km, which accounts for 82.31% of its total geographical area, while the actual forest cover stands at 3,342.49 sq. km, representing 47.11% of the state's land (FSI, 2021).

Considering Sikkim's extensive forest resources, the scope and feasibility of carbon finance projects such as Afforestation, Reforestation, and Revegetation (ARR), Reducing Emissions from Deforestation and Forest Degradation (REDD+), and Improved Forest Management (IFM) need to be thoroughly assessed.

ARR projects focus on afforestation or reforestation on non-forest or degraded forest lands, requiring that the designated project areas remain classified as non-forest for at least 10 years [60]. REDD+ projects, in contrast, aim to reduce emissions by preventing deforestation and forest degradation, focusing on forested lands subject to anthropogenic pressure [61]. IFM projects concentrate on improving forest management practices to enhance carbon sequestration, primarily on timber-harvesting forest lands, pushing beyond typical business-as-usual scenarios [29].

In this context, the Remote Sensing and GIS-based study assesses land-use and forest cover changes from 2009 to 2023. For ARR projects, areas that have remained non-forest for the last decade (2013-2023) were identified. For REDD+ and IFM projects, the study evaluates forest degradation patterns over the past 15 years (2009-2023) and assessing forest density changes through Fractional Vegetation Cover (FVC) analysis [53] as well as identifying driver of degradation through secondary literature survey and LULC analysis. GIS layers such as elevation, slope, aspect, and drainage further aid in delineating suitable project sites [15].

By leveraging satellite data and machine learning techniques for land-use & forest degradation mapping, this study provides a comprehensive understanding of forest transitions in Sikkim. The outcome of this analysis offers precise identification of potential carbon finance project sites, supporting sustainable forest management and carbon offset initiatives in the state.

About this Report

The Forest and Environment Department, Sikkim (hereinafter referred to as FED), had invited an RFP in the month of June 2023 to hire a Project Management Consultant (PMC) to assess the feasibility of the project to enter the carbon trading market, support in the development of a detailed Project Implementation Plan and drive the project through the entire lifecycle of carbon credit issuance, selling the carbon credits, as per the timelines and norms of the carbon credits market regulator. The FED Sikkim has awarded the Project to the joint consortium of ReNew Power Private Limited (RPPL), and The Energy Resources Institute (TERI). The entire project will be carried out in different phases and the current scope is for scoping study and feasibility assessment. This is the draft report which highlights the progress of scoping and feasibility study till September 2024.

Objective

The scoping and feasibility study for the identification of suitable carbon finance project sites in the state of Sikkim aims to achieve the following key objectives:

- Identification of eligible areas under Agriculture, Forestry and other Land Use (AFOLU) sector where carbon finance projects can be developed.
- Project plan of carbon project (s) as per carbon standard requirements and selection of suitable carbon offset standard(s) and methodology.

Specific objectives of this study would include the following points:

1. **Identify interventions/ schemes/ programs by Forest Department, that can be leveraged for carbon financing mechanism**
2. **Identification of Potential ARR Sites**
   To identify non-forest and degraded forest areas that have remained in such conditions for the past 10 years (2013-2023), making them suitable for Afforestation, Reforestation, and Revegetation (ARR) carbon finance projects.
3. **Delineation of Potential REDD+/IFM Project Sites**
   To delineate potential sites for Reducing Emissions from Deforestation and Forest Degradation (REDD+) and Improved Forest Management (IFM) projects within Sikkim's Recorded Forest Area (RFA) or designated forest lands, based on historical forest cover changes.
4. **Identification of Prominent Drivers of Forest Degradation**
   To identify the major anthropogenic and natural drivers responsible for forest degradation within Sikkim's forested areas over the period from 2009 to 2023, facilitating informed decisions on forest management interventions.
5. **Projection of Forest Degradation in a Business-as-Usual (BAU) Scenario**
   To project future forest degradation trends under a Business-as-Usual (BAU) scenario, assuming no project interventions, and assess the implications of such trends on forest health and carbon sequestration potential.
6. **Assessment of Project Development Suitability for Existing Plantation Sites**
   To evaluate the suitability of existing plantation sites established under government schemes for inclusion in carbon finance projects, with a focus on determining their potential for enhancing carbon sequestration through ARR or IFM methodologies.

Study Area

The project study area, Sikkim, is a small mountainous state located in the northeastern part of the country. It became the 22nd state of India after the dissolution of its monarchy in 1975 [49]. The total area of the state is 7096 sq. km. and is situated between latitudes 27°04'N to 28°07'48" N and longitudes 88°00'58" E to 88°55'25" E. It shares international boundaries with Tibet in the north and northeast, Bhutan in the east, and Nepal in the west. It shares a domestic (state) boundary with West Bengal in the south [49], [16]. It is the second smallest state in India after Goa [19] Initially, Sikkim consisted of 4 districts namely North Sikkim, East Sikkim, West Sikkim and South Sikkim. In December 2021, these 4 districts were renamed, and 2 more districts were carved out of the existing districts. Sikkim now consists of 6 districts: Mangan (formerly known as North Sikkim), Gangtok (formerly known as East Sikkim), Gyalshing (formerly known as West Sikkim), Namchi (formerly known as South Sikkim), Pakyong (carved out of East Sikkim district) and Soreng (carved out of West Sikkim district. The capital of Sikkim is Gangtok, located towards the southeastern part of the state [49]

The state of Sikkim is part of the Eastern Himalayas and is majorly mountainous with varied elevations from 300m to 8583m above mean sea level. The summit of Kanchenjunga, the world's third highest peak, is the state's highest point situated on the border between Sikkim and Nepal [16], [14] The state has 47.08% of its geographical area under forest cover [16]. It has two major rivers, the Teesta and Rangeet [22].

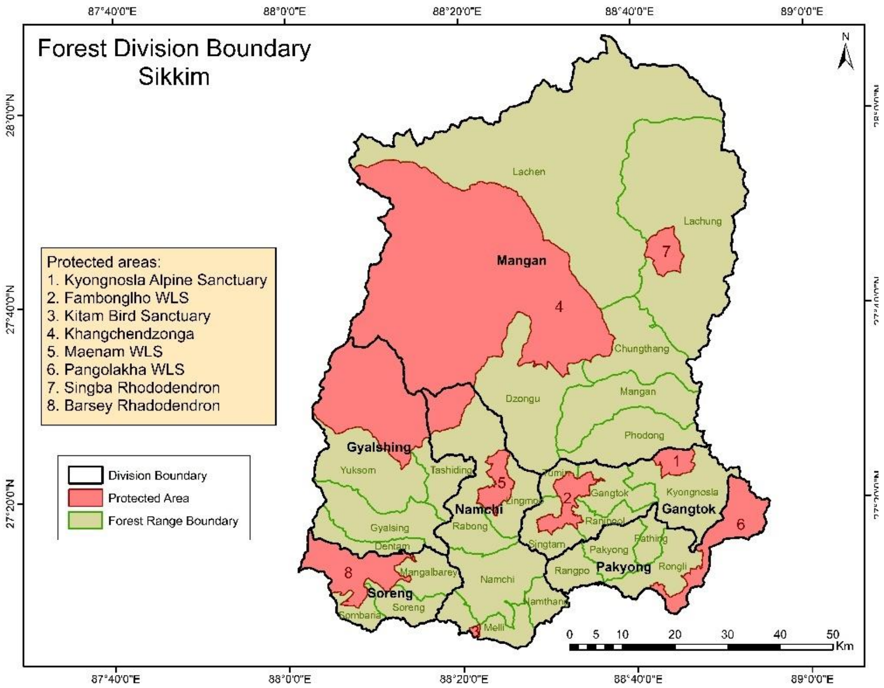


Figure 1 Forest Division Boundary, Sikkim; Prepared by TERI

The climate of the state ranges from sub-tropical in the south to tundra in the north [53] For most of the year the climate is cold and humid as rainfall occurs every month [16]. The major seasons include the cold weather season from December to February, spring season from March to May, monsoon season from June to September and retreating monsoon season from October to November [20]. Sikkim receives an average annual rainfall of 500 cm, the highest in the Eastern Himalayas. Due to its proximity to the Bay of Bengal and direct exposure to southern monsoon, it is the most humid region in the entire range of Himalayas. Fog becomes a common feature in monsoon and winter. The temperature varies with altitude and slope. The mean temperature varies from 4.5°C to 18.5°C in low altitude areas and 1.5°C to 9.5°C in higher altitude areas. During winter, snowfall is common in high altitude areas with extremes of temperature [16].

The soil of Sikkim consists of large amounts of iron oxide. The weathering of gneiss and schist found in the hills produces brown clay soils. Weathering of the rocks coupled with heavy rainfall causes soil erosion, soil nutrient loss through leaching and landslides. The soil type varies from neutral to acidic. The soil quality is coarse, poor and shallow and lacks organic and mineral nutrients [16], [38]. Most of the area has rocky, precipitous slopes which makes the land unfit for agriculture. However, by means of terrace farming some hill slopes have been used for agriculture [38]. The important mineral resources of the state include copper, lead, zinc, silver, dolomite, quartzite, soapstone, limestone and marble [29].

Sikkim has one high altitude National Park cum Biosphere Reserve and six wildlife sanctuaries [16]. This along with the wide variety of flora and fauna of Sikkim makes it an ecological hotspot of the lower Himalayas.

Profile of Sikkim

The topographical profile of Sikkim is characterized by a remarkable diversity in elevation, slope, and drainage patterns, reflective of its complex mountainous terrain. The elevation in Sikkim ranges from as low as 207 meters in the southern districts, such as Soreng, Namchi, Gangtok, and Pakyong, to a maximum of 8003 meters in the northern regions, where Mount Kanchenjunga is located (Figure 2.a). This steep altitudinal gradient is depicted in contour maps (Figure 2.c), where contours are classified into six distinct ranges, illustrating a gradual rise in elevation from the southern lowlands to the northern highlands. The highest elevations are concentrated along the northwestern border of the state, home to the Kanchenjunga massif and other significant peaks.

Slope analysis (Figure 2.d) reveals that the terrain of Sikkim is predominantly steep, with five slope classes ranging from very gentle (0–10 degrees) to very steep (41–87 degrees). The southern part of the state exhibits gentler slopes, while the central and northern regions are characterized by steep to very steep gradients. These steep slopes contribute to high surface runoff and limited soil infiltration, factors that are critical for hydrological processes and soil erosion. Conversely, areas with gentle slopes in the southern regions offer more conducive conditions for agricultural activities due to better water retention and less runoff. The aspect, or directional orientation of slopes, is varied across the region, with slopes facing different cardinal directions due to the rugged topography, influencing local microclimates and land use patterns.

The drainage system of Sikkim is closely aligned with its topographical features (Figure 2.e). The state's hydrological network follows a hierarchical stream order, with smaller tributaries merging to form higher-order streams. The two principal rivers, Teesta and Rangeet, represent the highest stream order and dominate the region's drainage system. The drainage pattern is primarily rectangular and parallel, largely determined by the underlying geological structures. These rivers and their tributaries play a crucial role in shaping the state's valleys and influencing land use, while also serving as vital water sources for agriculture and settlements. This intricate interplay of elevation, slope, aspect, and drainage defines Sikkim's unique geomorphological and environmental characteristics, with significant implications for land management, agriculture, and ecological sustainability.

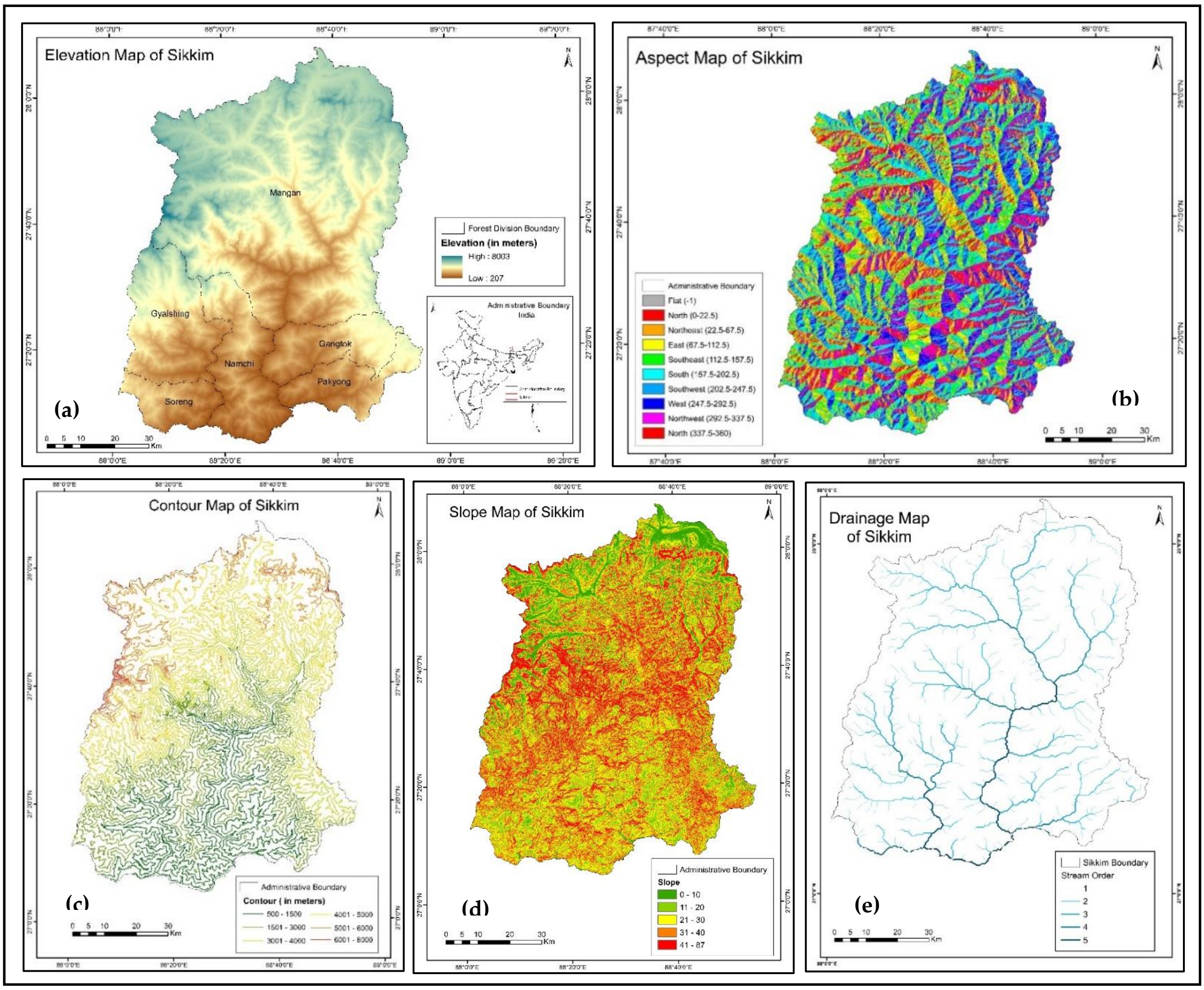


Figure 2 Study Area Maps; (a) Elevation, (b) Aspect, (c) Contour, (d) Slope, (e) Drainage; Prepared by TERI

Approach and Methodology

The scoping study will cover the entire Sikkim, aimed at comprehending the project's necessity and scope. This will cover the probable areas for monetization of the project, understanding the possible project types, the land use scenarios, state schemes, and policies that can be leveraged, etc. It will use data, filters, and GIS/RS analysis to eliminate the eligible and ineligible areas and activities. The results from the scoping study will further feed into the feasibility assessment for the project.

Target Sectors: To identify the target and probable areas for doing carbon monetization projects the land use pattern of the entire state will be studied covering the agriculture sector, forest sector, wetlands, and agroforestry.

AFOLU Carbon Project Types: Based on the land use pattern the eligible land will be identified in the below project categories under the AFOLU sector:

1. Afforestation, Reforestation, and Revegetation (ARR)
2. Reducing Emissions from Deforestation and Forest Degradation (REDD+)
3. Improved Forest Management (IFM)
4. Wetland Restoration and Conservation (WRC)

The following approach was used for this study:

Consultations with key departments: All the relevant departments of the Sikkim Government like the Forest and Environment Department, Horticulture, etc. are identified that can provide in-depth knowledge about the diversity of the area. A meeting was organized with the departmental personnel to gather existing knowledge and insights into the various sectors that can contribute towards generating carbon credits.

Review of existing programs/ interventions by State: A comprehensive review of published literature, scientific journals, and reports is in process to compile the existing knowledge on the carbon offset of the entire project area. All the gaps in the information and research areas are being identified to provide a focus on them during the assessment.

Detailed analysis of the information received: The information that is received from the department is analysed. The checks will be based on the mandatory requirements of the standards and methodology from the voluntary carbon market platforms.

Remote Sensing Analysis: The methodology for this scoping and feasibility study integrates Remote Sensing (RS) and Geographic Information System (GIS) technologies to identify suitable project sites for REDD+, Improved Forest Management (IFM), and Afforestation, Reforestation, and Revegetation (ARR) projects in Sikkim. It involves a spatio-temporal analysis of forest degradation trends, land-use transitions, anthropogenic drivers, forest fire incidents, agricultural expansion, and population distribution near forest areas. Additionally, forest-type classifications are incorporated for detailed forest strata preparation.

Given below is a detailed flow-chart of the methodology developed for the Feasibility Assessment and Delineation of project sites for the Development of Carbon Finance Project for Sikkim:

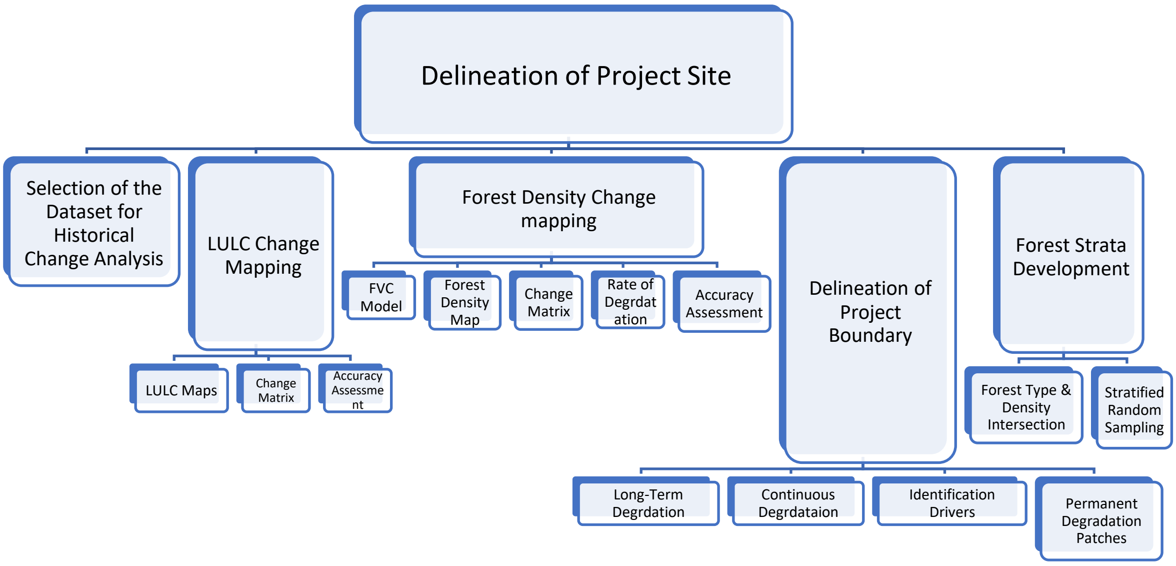


Figure 3 Delineation of Project Sites

Selection of the Dataset for Historical Change Analysis

Cloud free (less than 20% cloud coverage) multitemporal & multispectral satellite data sets have been selected for analysing the historical change both in terms of Land Use Land Cover (LULC) and Forest Density (FD) for delineating the project sites based on degradation rate.

The time span for the LULC & FD change analysis was selected after taking into consideration of all regional and national policies, forest laws, and trends that may have a considerable impact on forest carbon.

Data sets meet the following requirements:

- The selected datasets must be of the same spatial resolution (not less than 30 m), same season, or of the same expected phenological variations to maintain uniformity.
- The LULC & FD change analysis must start no more than 30 years prior to the baseline year (i.e., project start date) (For REDD+ & IFM).
- The change analysis must start no less than 10 years before the project start date (for REDD+ & IFM).
- The change analysis must start 10 years before the project start date (for ARR)
- The change analysis must include at least 4 points to be considered for the historical LULC change analysis (for REDD+ & IFM).
- The change analysis must include at least 2 points to be considered for the historical LULC change analysis (for ARR).
- The time points must be at least 4 years apart.

- At least one dataset must be within a year of the project start date.

LULC Change Mapping

Land use land cover (LULC) changes play a significant role in monitoring the land cover change dynamics at local, regional as well as national level. Land cover is what covers the surface of the earth and land use describes how the land is used.

Geographic Information System (GIS) along with the satellite Remote Sensing data provide good results in classification, quantification as well as change detection of different LULC classes for the study area. After acquisition of cloud free multitemporal & multispectral satellite data of same spatial resolution (not less than 30 m), image correction was carried out for the conversion DN value to reflectance value (surface reflectance/TOA reflectance). For LULC classification, corrected image where each pixel value represents reflectance value were used. Prominent land-use and land-cover (LULC) strata present at the project site were identified at the project start date (i.e., baseline year). The sampling and stratification strategy follows regional/national strategies, or one that is in line with IPCC and international guidelines [28], [29] . LULC Stratification also consider LULC classification as per the national classification scheme, and considers all six IPCC classes (forest, cropland, grassland, wetlands, settlements, and other land). Major forest types within the project area were also considered. Non-forest land was further stratified in strata representing different non-forest classes. IPCC land classes used for national GHG inventories was used to define such classes. However, where appropriate, additional, or different sub-classes were specified.

Flowchart for the Land use land cover maps and change detection methodology have been shown in Fig. 4:

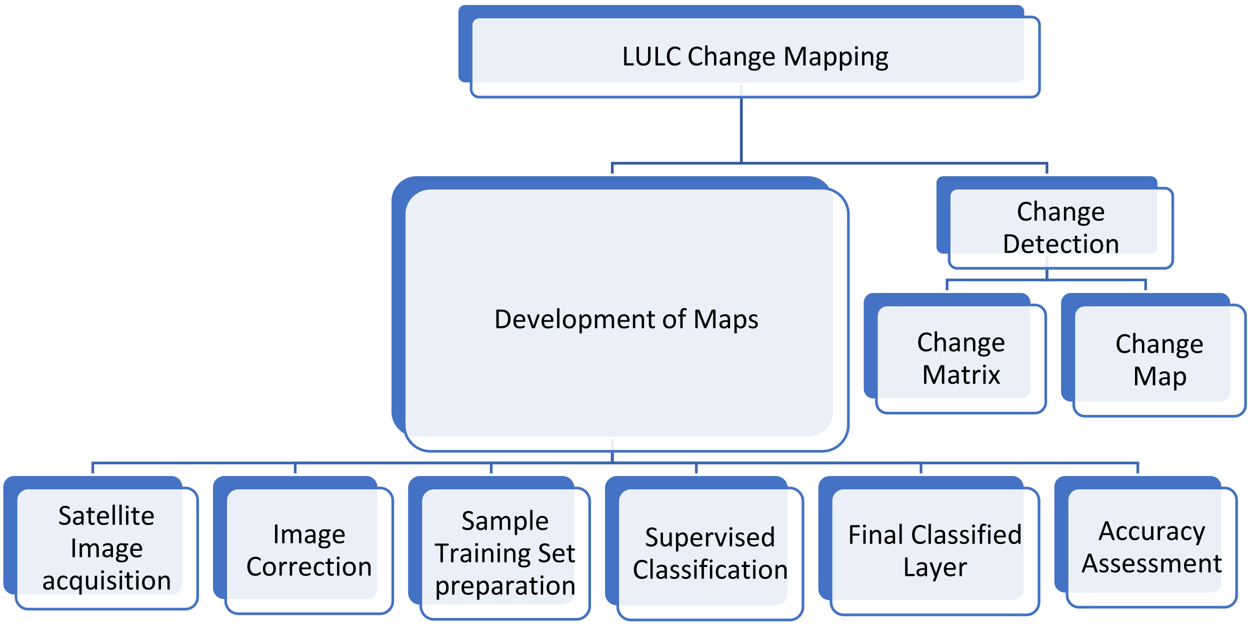


Figure 4 Flowchart of methodology adopted for LULC Map development

For generating the LULC maps for Sikkim, Satellite imagery from Landsat 5 TM, and Landsat 8 OLI/TIRS for the years 2009, 2013, 2017, 2021 and 2023 were used (Table 2).

Due to excessive cloud cover throughout the year, single-date images were used for the analysis. For the years 2009 the Landsat 5 TM data whereas for the years 2013, 2017, 2021, and 2023 the Landsat 8 (OLI/TIRS) data were downloaded from USGS Earth Explorer. The spatial resolution of all the downloaded Landsat data was 30m (Table 1).

Acquisition Date	Data Source	Type	Resolution	Sensors	Coordinate Reference System
08-12-2009	**Landsat 5**	Multispectral	30 m	ETM+	WGS_1984_UTM_Zone_45N
20-11-2013	**Landsat 8**	Multispectral	30 m	OLI	WGS_1984_UTM_Zone_45N
16-02-2017	**Landsat 8**	Multispectral	30 m	OLI	WGS_1984_UTM_Zone_45N
20-12-2021	**Landsat 8**	Multispectral	30 m	OLI	WGS_1984_UTM_Zone_45N
16-11-2023	**Landsat 8**	Multispectral	30 m	OLI	WGS_1984_UTM_Zone_45N

Table 1 Data Acquisition for LULC

S.NO	Resolution	Band Name	Wavelength (micrometres)		Useful for mapping
			TM/ETM+	OLI	
1	30 m	Blue	0.45-0.52	0.45-0.51	Distinguishing soil from vegetation and deciduous from coniferous vegetation
2	30 m	Green	0.52-0.60	0.53-0.59	Emphasizes peak vegetation, which is useful for assessing plant vigour
3	30 m	Red	0.63-0.69	0.64-0.67	Discriminates vegetation slopes
4	30 m	NIR	0.76-0.90	0.85-0.88	Emphasizes on biomass content
5	30m	SWIR	1.55-1.75	1.57-1.65	Discriminates moisture content of soil and vegetation; it is capable of penetrating thin clouds

Table 2 Resolution of Bands taken for the study

Processing Of Remote Sensing Data

Image Correction

The task used multi-spectral data from the Landsat series for Land Use Land Cover (LULC) and Fractional Vegetation Cover mapping. The geometrically co-registered (with sub-pixel accuracy) open-source cloud-free Landsat data form the main data for our analysis. The Landsat images with the least cloud cover were downloaded from the United States Geological Survey (USGS) using Google Earth Engine (GEE).

Landsat datasets used are processed to Systematic Terrain Correction (L1GT) which is created when the systematic product has consistent and sufficient locational accuracy to permit the application of a terrain model. The L1GT provides systematic, radiometric, and geometric accuracy, which employs a Digital Election Model (DEM) to correct for relief displacement. The accuracy of these data products is attributed pointing accuracy of the spacecraft, and thus terrain correction helps to account for the higher order/relief induced distortion event when GCP are not used, thus it is typically better than one pixel. The pre-processing of Landsat data includes the following steps: - firstly, all the remote sensing data downloaded from United States Geological Survey (USGS) Earth Explorer using GEE (https://earthexplorer.usgs.gov/) were projected in the UTM projection system (datum WGS 1984, 43 N zone) and pre-processed for noise reduction, radiometric correction & calibration, and atmospheric correction. Variations in the sun's azimuth, atmospheric conditions and sensor response influence the reflectance of the land surface. The noise persists in most of the satellite images due to sensor malfunctioning and heating, and environmental influences reduce the quality of the data. Hence, suppression of noise contents in an image is essential to enhance the quality of the data. The distributed remote sensing images usually contain the digital number, which is a calibrated radiance value by sensor-specific gain and offset. Thus, radiometric correction and calibration are required to convert digital numbers to Top of Atmosphere (TOA) radiance. Further, atmospheric correction is performed to reduce the effects of atmospheric scattering and absorptions in the radiance data and convert the radiance into TOA reflectance data. The study area was masked and clipped from the composite multitemporal images by using the extraction by mask tool of ArcGIS 10.8. Each subset image was enhanced using the histogram equalization technique to improve spectral responses.

Image Classification

A thorough scanning of earlier published literature and maps on LULC of the project area was carried out including the information available with the State Forest Department. Google Earth Images and Landsat Satellite data were reviewed for different seasons and dates to define a classification scheme for satellite data classification. Using outcomes of the review of published literature, forest inventory reports from the State Forest Department, land use and eco-zones maps, distribution of biomes and taking account of the focus of the study, a classification scheme was designed to assess the satellite data for mapping LULC. The classification strategy includes classes such as Forest, Agriculture, Barren and Open land, Waterbody, Snow and Settlements. The LULC classes along with the definition have been presented in Table 3. The proposed classification scheme offers consistency owing to the LULC distribution in the study region. Each class is mutually exclusive hence there are the least chances of confusion and overlaps.

In addition to information gathered from ground truthing through high-resolution satellite images such as Google Earth images for visual interpretation and sample training set preparation. Satellite data (in False Colour Composite using NIR, Red and Green, and True Colour Composite using Red, Green and Blue) along with Google Earth Images of very high resolution were reviewed. In the absence of ground truth and a-prior knowledge, no statistical tools/sampling strategies were used. Instead, the maximum possible training sets were generated using the Google Earth images to have better control over the image for classification. While reviewing, the scales of 1:50,000 were kept constant. Using the classification scheme defined above, areas which could be potentially used for the training and testing sets were identified on the satellite data. The exercise was independently carried out for the years 2000 through 2023. These were further checked with the published maps and literature including the field photographs on Google Earth and other websites. Area/Region of Interest (A/ROI) polygons were generated for each of the validated sites on the Landsat data while referring to the Google Earth images. The distribution is roughly proportional (around 0.005 % to 0.01% of the area) to the area covered by the respective classes, the availability of photographs and the focus of the study for the mapping exercise.

Here, the Random Trees Classifier (RTC) algorithm has been used for the supervised image classification. The Random Trees classification method is a supervised machine-learning classifier based on constructing a multitude of decision trees, choosing random subsets of variables for each tree, and using the most frequent tree output as the overall classification. RTC is a collection of individual decision trees in which each tree is generated from different samples and subsets of the training data. The main reason behind it is that for every pixel that is classified, several decisions are made in rank order of importance. The graph generated for each pixel looks like the branches of a tree. Moreover, when one classifies the entire dataset, the branches form a tree. This method is called random trees because here, classifying the dataset a number of times based on a random sub-selection of training pixels, resulting in many decision trees. To make a final decision, each tree has a vote. This process works to mitigate overfitting. Supervised classification using the RTC algorithm for the development of LULC Maps has been carried out using the spatial analyst tool in the ArcGIS 10.8 platform. The Kappa Coefficient for accuracy assessment of LULC maps was 0.81. The methodology adopted for image classification is presented as flowchart (Figure 5):

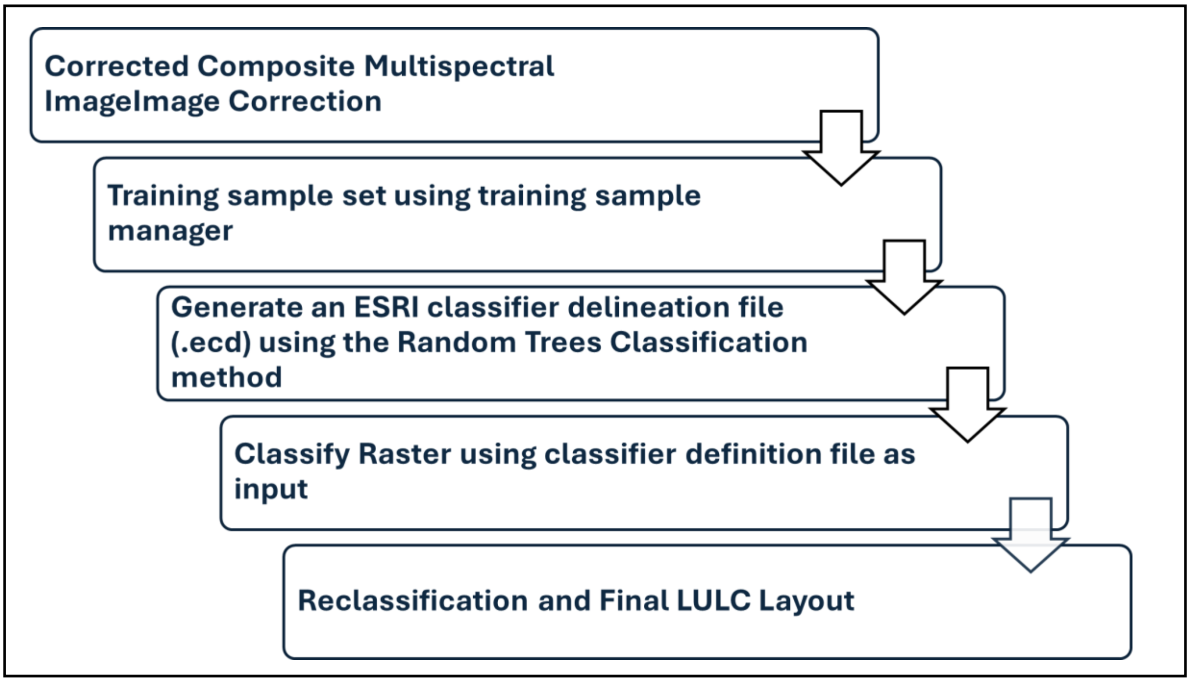


Figure 5 Training Samples for LULC

LULC Classes	Description
Settlements	Areas containing man-made structures and other homogenous impervious surfaces like buildings, housings, roads, industries and rail networks
Agriculture	Land parcels with a geometrical shape (rectangular/square) containing crops planted by humans which are not at tree height.
Waterbody	This includes the region where water is present predominantly throughout the year. It takes into account both natural and man-made water sources like rivers, ponds and canals
Barren & Open Land	Encompasses areas with dispersed and discrete vegetation, barren land, rocky landscapes, and both homogeneous and heterogeneous grassland.
Snow	Large homogenous areas of permanent snow or ice, typically only in mountain areas or highest latitudes.
Forest Green	Areas with significant clustering of tall vegetation (trees) with a dense or closed canopy, also include naturally grown tree cover outside forest areas

Table 3 LULC Classes for Sikkim

Forest Density Change Mapping

Forest density maps must be developed either based on Fractional Vegetation Cover (FVC) map using spectral un-mixing algorithm or vegetation indices-based Forest Canopy Density (FCD) model.

Fractional Vegetation Cover (FVC):

Fractional vegetation cover (FVC) is defined as the projected percentage of the total study area that is vegetated (roots, stems, and leaves) [18]. FVC not only reflects the size of the plant's photosynthetic area and the density of vegetation growth but also represents the growth trend of vegetation to some extent [17]. FVC plays an important role in climatic, hydrologic, and geochemical cycles [30] and is widely used to describe vegetation quality and ecosystem change. It is also a controlling factor in transpiration, photosynthesis, global climate changes and other terrestrial processes and climate models. The development of geospatial technology has provided a promising tool for FVC calculation. Among all the estimation methods, the Linear Spectral Un-Mixing (LSU) model has been widely used to estimate FVC.

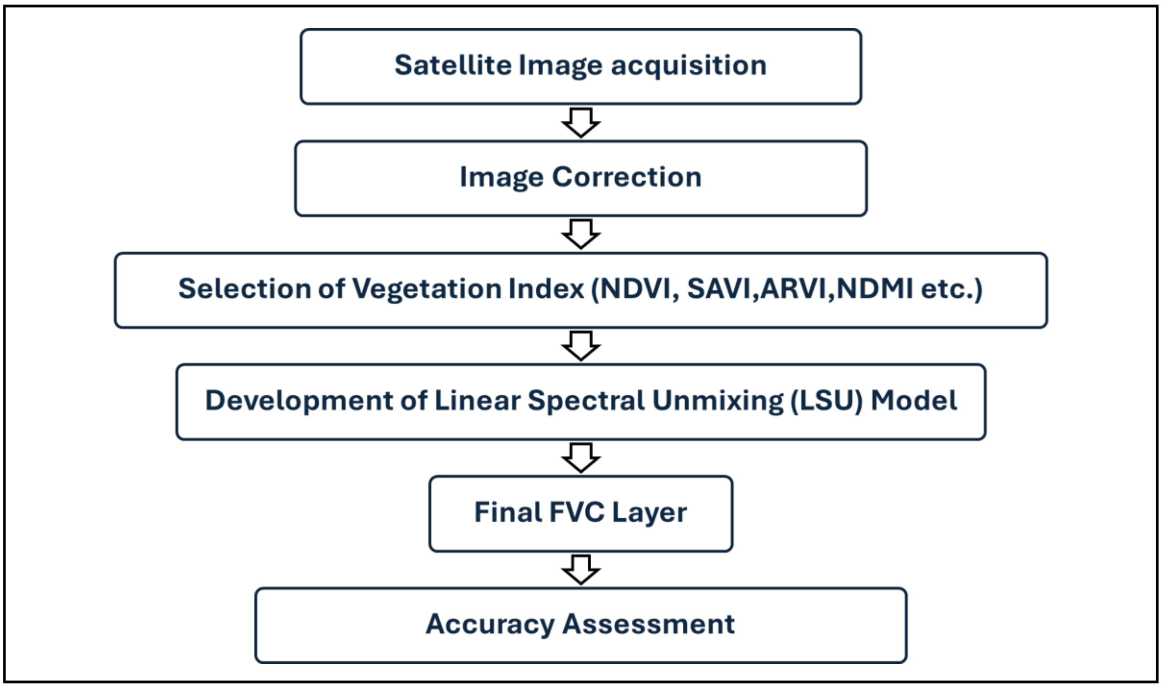


Figure 6 Flowchart of methodology adopted for FVC Map development

Selection of Vegetation Index (NDVI, SAVI, ARVI, NDMI etc.)

Widely, the Normalized Difference Vegetation Index (NDVI) is used to compute the FVC. The NDVI is computed using the equation (NDVI = NIR - Red/NIR + Red). The NDVI formula combines the information available in the red and NIR bands into a single and representative value. NDVI helps assess vegetation health and stress. Also, the combination of NDVI with Red and NIR bands enhances the satellite data for differentiating vegetation classes from non-vegetation classes. The NDVI value ranges from -1 to +1. Higher values of NDVI indicate the highest possibility of vegetation density. Bare soil is represented with NDVI values which are closest to 0 and water bodies are represented with negative NDVI values [23], [9], [49], [64].

Development of Linear Spectral Unmixing (LSU) Model

In LSU model the reflectance of each pixel is assumed to be the sum of the reflectance of all subpixel components, weighted by their percentage cover. These components are referred to as end members in the present work. According to DeFries et al. 2000 [13], the equation can be written as

$$R_i = \sum_{j=1}^{n} r_{ij} F_j + e_i \qquad (1)$$

where R_i is the reflectance of one pixel in band i, r_{ij} is the reflectance of end member j in band i, and F_j is the percentage cover of end member j in such pixel. The term e_i is introduced to account for some insignificant remaining components within the pixel in this band.

In this attempt, each pixel of the Landsat imagery in the forest area of the project site is assumed to consist of two components: vegetation canopies and Bare soil. The LSU model then becomes a two-component linear model. The reflectance values of these two components are independent of each other. Then Equation (1) can be written as

$$R = R_{canopy}FVC + R_{Baresoil}(1 - FVC) + e \quad (2)$$

where FVC is the fractional vegetation cover in one pixel. Error term "e" represents insignificant remaining components within the pixel in each band. Equation (2) indicates that the total spectral response of a pixel at a certain wavelength is a linear combination of responses from its vegetation canopy and bare soil area, weighted by the corresponding cover of each component, FVC and (1 − FVC), respectively. The spectral signatures of surface targets vary significantly with wavelengths. Using different spectral bands may result in various fractional cover values (Maas, 2000). Even at certain wavelengths, the values of R_{canopy} and $R_{Baresoil}$ are highly influenced by vegetation wetness, structure, soil moisture, texture, and external factors such as sun–target–sensor geometry [58]. To reduce these problems, various studies were carried out [24], [65], [47] where vegetation indices had been used in FVC estimation. For tropical forests, the two-component endmember assumption is close to reality, and therefore the error term can be ignored. By using NDVI as the proxy for all types of vegetation indices and replacing the spectral response R, Equation (2) becomes

$$NDVI = NDVI_{canopy}FVC + NDVI_{Baresoil}(1 - FVC) \quad (3)$$

Where, $NDVI_{canopy}$ indicates the 100 % canopy cover (i.e., vegetation gap fraction is zero) endmember whereas $NDVI_{Baresoil}$ indicates the bare soil endmember where vegetation gap fraction is 100%. Then FVC can be expressed as

$$FVC = \frac{NDVI - NDVI_{Baresoil}}{NDVI_{canopy} - NDVI_{Baresoil}} \quad (4)$$

Where NDVI is the input from NDVI layer prepared to develop FVC.

The two endmembers $NDVI_{canopy}$ & $NDVI_{Baresoil}$ in Eq. 3 were calculated as the mean in each NDVI layer prepared for all the years of analysis.

FVC can be further expressed in terms of percentage as:

$$FVC\ (in\ \%) = \frac{NDVI - NDVI_{Baresoil}}{NDVI_{canopy} - NDVI_{Baresoil}} * 100 \quad (5)$$

Development of Fractional Vegetation Cover Map

The vegetation Fraction layer for each time point of historical change analysis would have to be developed in the GIS platform using the LSU model.

Where FVC (in %) < 20 have been removed using raster calculator and delineated as the non-Forest.

Then FVC (in %) was rescaled from 0 to 100 percent using spatial analyst tool and categorized into forest classes (i.e., Very Dense, Moderate Dense, Open Forest and Scrub) based on ISFR definition of forest classes.

A final map layout was prepared by incorporating the Forest (i.e., Very Dense, Moderate Dense, Open Forest and Scrub) and Non-Forest Classes (i.e., the area delineated as non-Forest) for all the years of analysis.

Class	Description
Very Dense Forest	All Lands with tree cover of canopy density of 70% and above
Moderately Dense Forest	All lands with tree cover of canopy density between 40% and 70% above
Open Forest	All lands with tree cover of canopy density between 10% and 40%
Scrub	All forest lands with poor tree growth mainly of small or stunted trees having canopy density less than 10 percent
Non-Forest	Any area not included in the above classes with negligible or no canopy cover

Table 4 FD Analysis Classes

Acquisition Date	Data Source	Type	Resolution	Sensors	Coordinate Reference System
01-01-2009 to 31-12-2009	**Landsat 5**	Multispectral	30 m	ETM+	WGS_1984_UTM_Zone_45N
01-01-2013 to 31-12-2013	**Landsat 8**	Multispectral	30 m	OLI	WGS_1984_UTM_Zone_45N
01-01-2017 to 31-12-2017	**Landsat 8**	Multispectral	30 m	OLI	WGS_1984_UTM_Zone_45N
01-01-2020 to 31-12-2020	**Landsat 8**	Multispectral	30 m	OLI	WGS_1984_UTM_Zone_45N
01-01-2021 to 31-12-2021	**Landsat 8**	Multispectral	30 m	OLI	WGS_1984_UTM_Zone_45N
01-01-2022 to 31-12-2022	**Landsat 8**	Multispectral	30 m	OLI	WGS_1984_UTM_Zone_45N
16-11-2023	**Landsat 8**	Multispectral	30 m	OLI	WGS_1984_UTM_Zone_45N

Table 5 Data Acquisition for FD analysis

Change Matrix for historical Forest Density Change detection:

Change detection quantifies the changes that are associated with FD changes in the landscape using geo-referenced multi-temporal remote sensing images acquired on the same geographical area between the considered acquisition dates [49]. An important aspect of change detection is to determine what is changing to what category of FD type (i.e., which FD type is changed to the other type of FD class). FD change matrix depicts the change in area from one class to another FD type that remains as it is at the end of the period. Thus, to clearly understand the source and destination of major FD changes, the change matrix for each period was analysed. For change analysis, change matrices were generated for the different time periods to analyse changes in the area covered by different FD classes. This was done by comparing the number of pixels falling into each category of FD in one time period with the categorization of the same pixels in the same/different class in the previous time period.

Change in classes = MATRIX (time 1, time 2)

The data gathered from the generated matrix were further rearranged to prepare the FD change matrix. Forest density change maps were prepared for each of the two consecutive time periods by intersecting FD maps of two successive time periods. Changes in FD classes between two years were analysed through the change maps generated.

The diagonal cells of the matrix in the change matrix tables represent the area that has remained the same in both time periods. Other cell values represent the area that has changed from one class to another class.

Class	Definition
Afforestation	Afforestation is the direct human-induced conversion of land that has not been forested, for a period of few decades, to forested land through planting, seeding, and/or the human-induced promotion of natural seed sources
Deforestation	It is the direct human-induced conversion of forested land to non-forested land. Deforestation is also marked as the drastic decrease in carbon forest carbon stock in forest strata
Enhancement	Increase in the density or average size of trees in a stand. Consequently, enhancement indicates the increase in the carbon stock in forest strata
Degradation	The direct human-induced long-term reduction of the overall potential supply of benefits from the forest, which includes carbon, wood, biodiversity, and other goods and services

Table 6 Forest Density Change Classes

Rate of Forest Degradation:

The annual rate of forest degradation was calculated by computing the ratio between the change in area from the higher forest density class to the lower forest density class and the period in which that change has taken place (in years).

Rate of Degradation: ($FD_i \rightarrow \sum FD_{j,k,l}$) in ha/years; where i>j,k,l

The annual rate of forest degradation was calculated from the initial year to each successive time point of assessment till the baseline year. Forest degradation maps were prepared for each successive time point of analysis using the dynamics of the forest density classes, i.e., change from one density class to another.

Accuracy Assessment

The accuracy of spatial data has been defined by the United States Geological Survey (USGS) as: "The closeness of results of observations, computations, or estimates to the true values or the values accepted as being true" (USGS, 1990).

Here, for accuracy assessment of the LULC & FD layers, the user's accuracy, producer's accuracy, overall accuracy, and kappa coefficients have been computed.

Overall Accuracy essentially indicates that out of all of the reference sites what proportion were mapped correctly. The overall accuracy is usually expressed as a percent, with 100% accuracy being a perfect classification where all reference sites were classified correctly. Overall accuracy is the easiest to calculate and understand but ultimately only provides the map user and producer with basic accuracy information. Overall accuracy can be calculated using the following formula:

Overall Accuracy = (Total Number of Correctly Classified Pixels (Diagonal))/ (Total Number of Reference Pixels) ×100

The User's Accuracy is the accuracy from the point of view of a map user, not the map maker. The User's accuracy essentially informs about how often the class on the map will be present on the ground. This is referred to as reliability. The User's Accuracy is complementary of the Commission Error, User's Accuracy = 100%-Commission Error. The User's Accuracy is calculated by taking the total number of correct classifications for a particular class and dividing it by the row total. User accuracy can be estimated by using the following formula:

Users Accuracy = (Number of Correctly Classified Pixels in each Category)/ (Total number of Classified Pixels in that Category (The Row Total)) ×100

Producer's Accuracy is the accuracy of the map from the point of view of the map maker. This is how often are real features on the ground correctly shown on the classified map or the probability that a certain land cover of an area on the ground is classified as such. The Producer's Accuracy is complementary of the Omission Error, Producer's Accuracy = 100%-Omission Error. It is also the number of reference sites classified accurately divided by the total number of reference sites for that class. Producer accuracy can be calculated by using:

Producer Accuracy = (Number of Correctly Classified Pixels in each Category)/ (Total Number of Reference Pixels in that Category (The Column Total)) ×100

Errors of omission refer to reference sites that were left out from the correct class in the classified map. The real land cover type that was left out or omitted from the classified map indicates the errors of omission. An error of omission in one category will be counted as an error in commission in another category. Omission errors are calculated by reviewing the reference sites for incorrect classifications.

Errors of commission are in relation to the classified results. These refer to sites that are classified as reference sites that were left out (or omitted) from the correct class in the classified map. Commission errors are calculated by reviewing the classified sites for incorrect classifications.

The Kappa Coefficient (T) consists of a multivariate measure of agreement between rows and columns of the error matrix. It essentially evaluates how well the classification performed as compared to just randomly assigning values, i.e., whether the classification does better than random or not. The value of the Kappa Coefficient ranges from -1 to 1. A value of 0 indicates that the classification is no better than a random classification. A negative number indicates the classification is significantly worse than random. A value close to 1 indicates that the classification is significantly better than random. The Kappa Coefficient can be calculated by using the following formula:

Kappa Coefficient (T) = ((TS×TCS)-∑ (Column Total × Row Total))/ (TS^2-∑ (Column Total x Row Total))

where, TS = Total sample and TCS =Total Corrected Sample

Delineation of Project Boundary

Delineation of ARR Project Sites

The identification of ARR sites focused on mapping areas that have remained non-forest or degraded forest for a continuous period of 10 years (2013-2023). These areas were prioritized for afforestation and reforestation activities.

- ***Land Transition Analysis:***

  LULC Change Detection: A change detection analysis was conducted to track transitions between forest and non-forest land over the past decade. Supervised classification (e.g., Support Vector Machines, Random Forest) identified areas that had not undergone significant regeneration, making them suitable for ARR interventions.

  Non-Forest Persistence Mapping: Areas that remained barren or degraded from 2013 to 2023 were mapped as potential ARR project sites.

- ***Evaluation of Government Plantation Sites:***

  Existing plantations established under various government schemes, such as the Green India Current Mission (GIM) or Compensatory Afforestation schemes, were evaluated to assess their potential for inclusion in ARR carbon finance projects. High-resolution satellite imagery and field data were used to assess the success, growth, and carbon sequestration potential of these plantations.

Delineation of REDD+ and IFM Project Sites

This approach integrates long-term forest degradation trends, continuous forest degradation layers, and the identification of key anthropogenic drivers of degradation, derived from historical LULC analyses. The methodology ensures accurate delineation of project sites by assessing both short-term and long-term forest degradation dynamics and computing the contribution of human-induced drivers to forest degradation.

- ***Long-Term Forest Degradation Analysis***

  Long-term forest degradation was analyzed through a forest density change matrix generated from two successive time points within the historical change analysis period (2009-2023). This method provided a clear understanding of how forest density has changed over time due to degradation. Four change maps were created for two consecutive periods within this time span, using remote sensing data to detect variations in forest density. These maps were overlaid to develop a composite long-term degradation map that represents areas of significant forest degradation over the last 15 years. A final long-term degradation layer was prepared by integrating FD change maps across four successive periods (e.g., 2009-2013, 2013-2017, 2017-2020, 2020-2023). The areas exhibiting persistent declines in forest density were highlighted as critical zones for REDD+ and IFM interventions, where emissions from deforestation can be reduced, and improved forest management practices can enhance carbon sequestration. For IFM, this analysis is applied specifically to logged forests or areas under active timber management. Identifying long-term degradation trends helps determine where improved forest management practices can optimize timber harvesting while enhancing carbon sequestration.

- ***Continuous Degradation Analysis***

  Continuous degradation was assessed by analysing forest density changes for three successive years leading up to the baseline year (2023). The FD change matrix for these three years provided insights into areas experiencing ongoing forest degradation, essential for identifying sites suitable for REDD+ and IFM projects. A continuous degradation map was prepared, marking forested areas where degradation was ongoing in a short-term, consecutive manner. This map highlights areas with immediate degradation risks and the need for intervention through REDD+ projects, which focus on reducing emissions from deforestation and degradation. For IFM, continuous degradation analysis highlights areas under timber harvesting that are being degraded by unsustainable practices.

- ***Overlaying Initial and Final Degradation Patches:***

  To identify areas of permanent degradation, the long-term and continuous degradation patches were overlaid with the initial degradation map (based on FD changes from 2009) and the final degradation map (based on FD changes in 2023). This step ensures the consistency of the degradation patches over time, confirming areas that have been subjected to long-term and continuous degradation. Areas that exhibited persistent degradation throughout the entire period (2009-2023) were classified as "permanent degradation" zones. These areas are highly suitable for

REDD+ projects, where restoration and management activities could mitigate further emissions and rehabilitate the forest ecosystem.

- *Identification of Anthropogenic Drivers of Degradation*

The drivers causing deforestation/forest degradation need to be identified and validated as a part of the REDD project development. Activities like firewood collection, timber extraction, land clearing for agriculture, unsustainable NTFP collection, etc. are largely responsible for forest degradation and deforestation.

Drivers of deforestation and forest degradation fall into two categories - first, those that are planned and projected in accordance with policies, legal framework management plans, etc., and second, that are unplanned and spontaneous, beyond government and management control.

Planned Drivers	**Unplanned Drivers**
Infrastructure and other developmental works: • Road construction • Hydro-electric power • Irrigation projects • Industrial development • Expansion of cities and towns • Mining and stone quarry activities	Unauthorized activities, routine local unsustainable practices not covered in official management plans, and natural causes such as: • Encroachment of forest land for agriculture and housing • Unplanned felling • Unsustainable extraction of firewood, small timber and NTFP • Uncontrolled livestock grazing • Unsustainable fodder collection • Unplanned stone quarry operations

The focus for REDD project development is largely on the unplanned drivers. Based on the methodology, these will be validated and quantified.

➢ **Historical LULC Analysis**

Anthropogenic drivers of forest degradation were identified using historical LULC maps created for each time point of the analysis (2009, 2013, 2017, and 2023). Machine learning algorithms, such as Random Forest or SVM, were employed to generate these LULC maps with high accuracy, identifying land-use transitions and human activities contributing to forest loss and degradation. Key drivers, including forest fire incidents, increased agricultural activities, population distribution within forest fringe villages, and settlements or built-up development, were mapped and quantified.

➢ **Contribution of Each Driver**

Historical forest fire incidents and the expansion of agricultural land were specifically mapped to identify their spatial correlation with degraded forest areas. These drivers were found to have significant impacts on forest degradation, particularly in areas close to forest fringe villages. Spatio-temporal population distribution map was generated for villages located within the forest fringes, identifying human settlements that may exert pressure on the surrounding forests. These areas, where population growth has been associated with increased forest exploitation and agricultural expansion, were flagged for REDD+ and IFM project development to mitigate further degradation.

- **Fire Incidents: -**

Fire Point Intensity (FPI) is influenced by human activities such as collecting fuelwood, shifting agriculture, resin tapping, and natural factors like dry weather, high temperature, wind speed, vegetation moisture content, etc. Uncontrolled wildfires pose risks to the environment, economy, and human safety. They also emit significant particulate matter, impacting air quality, vegetation, and human health [42] .

Active fire products from the Moderate Resolution Imaging Spectroradiometer (MODIS) sensor have been accessed in shapefile format from NASA's Fire Information for Resource Management System (FIRMS) from January 2009 to December 2023. Using a contextual algorithm, the MODIS active fire product detects fires in 1 km pixels that are burning at the time of overpass under relatively cloud-free conditions. The spatial data has been processed in the ArcGIS software where hotspot analysis using the Brightness Temperature (T31) is done. According to Mupfiga et al. (2022) [42], hotspot analysis is a tool used to identify the high- or low-level clusters within a dataset. T31 represents the brightness temperature in the infrared spectrum, helping to estimate the background temperature associated with fire events. Getis-Ord GI detects spatial clustering, helping in locating fire hotspots or cold spots.

- **Population Growth: -**

Human settlement is identified by the presence of constructed manmade elements such as buildings, associated structures, and civil works. To calculate the human settlement in each grid cell, the built-up areas (Building 19 footprint area) are taken from the Landsat and Sentinel-2 imagery (upscaled to 30m). Raw census data with the geometry of the Gridded Population of the World, version 4.11(GPWv4.11), from CIESIN/SEDAC Census population data with a resolution of 250m, has been factored into the analysis. The GHSL method is then applied to integrate information from population censuses, and built-up areas, into a 1km grid. The final GHSL layer represents the presence and density of the population. Each grid cell value represents the absolute number of inhabitants (GHSL-POP). The spatial raster dataset depicts the distribution of the residential population, expressed as the number of people per cell. Residential population estimates between 1975 and 2020 in 5-year intervals and projections to 2025 and 2030 derived from CIESIN GPWv4.11 which were further disaggregated from census or administrative units to grid cells (spatial resolution-100 m). Here, the spatial distribution of the population in the state of Sikkim as well as within the recorded forest area (RFA) has been prepared for 4 corresponding epochs (2000 to 2030) using the GHSL population data having the spatial resolution of 100 meters to assess the variation in the spatial distribution of population numbers.

Forest Strata Development

For REDD+ & IFM, degraded forest land must be stratified based on forest types and density. One can use the nationally accepted canopy density classes with proper justifications for strata development. These classes may be further optionally subdivided based on spatial and spectral classification techniques as found suitable. The strata based on forest type and density would be used for GIS-based stratified random sampling for the project area. The same strata would be used further for the linear regression model development between predictor (FVC) and observed variables (forest biomass).

Results and Observations

Selection VCM Standard/ Scheme

The suitability of the VCM platform and thereby the selection of methodology is majorly dependent on the project activity and the existing scenario in an area. The following section highlights the various available platforms based on the type of activity that the project has to offer:

Afforestation, Reforestation, and Revegetation (ARR)

This describes projects that aim to boost carbon storage in trees and sometimes even soil. These projects achieve this by increasing or restoring vegetation cover. They can involve directly planting or sowing trees, or indirectly encouraging natural tree regrowth with human help. These types of projects can be done along with farmers on their agricultural lands as agroforestry, on barren/degraded lands, on community common lands, Gram Panchayat lands, and preferably with native species, bamboo, etc.

Applicability and eligibility criteria:

- The project area shall not be cleared of native ecosystems within the 10-year period prior to the project start date
- Projects are considered ineligible if standing biomass, which serves a similar purpose as the planting units in the project, has been removed within the last 10 years
- Occur within an area classified as non-forest for the past 10 years with less than 10 percent pre-existing standing biomass cover
- Occur in an area subject to continuous cropping[1], in “settlements”, or “other lands” land use category[2]

Under Phase 1, the most appropriate VCM platform will be selected. Priority will be given to Gold Standard and Rabobank’s Acorn Standard. These two will be assessed based on their requirements, complexities, document and evidence requirements, GIS/RS requirements, credit value, risk, etc. As a fall-back mechanism, VERRA will be considered.

VCM Platforms

Gold Standard

Gold Standard isn't a one-size-fits-all approach for environmental and social impact projects. It provides a framework with a variety of pre-approved methodologies tailored to specific project types, like renewable energy or sustainable agriculture. Each methodology outlines how to measure a project's benefits, such as reduced emissions or improved soil health. To ensure rigor and transparency, independent auditors assess project design against the chosen methodology and verify its impact after implementation. If successful, the Gold Standard issues certificates representing the project's positive environmental or social contribution, emphasizing stakeholder involvement and

[1] cultivation of an agricultural crop on the same site year after year, without any periods of fallow exceeding one season, demonstrated over 10 or more years prior to the project start date

[2] Land use category as defined by the IPCC Guidelines for National Greenhouse Gas Inventories Volume 4 AFOLU, Chapter 3 Consistent Representation of Lands.

alignment with UN Sustainable Development Goals. In addition, it also allows us to do impact projects utilizing its impact registry.

Acorn

Rabobank's Acorn program tackles climate change by empowering smallholder farmers in developing countries. It acts as a bridge, connecting these farmers with the international carbon market. Acorn's strategy hinges on transitioning these farmers to sustainable agroforestry practices. By integrating trees into their agricultural landscapes, farmers not only increase their income but also contribute to environmental benefits. Acorn facilitates this transition by providing technical support, helping farmers measure the carbon sequestration of their trees, and then issuing tradable carbon credits. These credits are then sold to companies seeking to offset their carbon footprint.

VERRA

VERRA functions like a comprehensive toolbox for validating the environmental benefits of various projects. Unlike a single method, VERRA offers a framework with a collection of approved methodologies. These methodologies cater to specific project types, such as forestry initiatives or water purification systems. Each methodology provides a detail for quantifying the project's positive environmental impact. This includes procedures for defining project boundaries, measuring emission reductions or removals, and ensuring the project's overall contribution is additional.

A preliminary comparison between the three platforms has been performed and presented below. The same will be further refined and updated.

Point of comparison	VERRA	Gold Standard	Acorn
Baseline Scenario	Performance benchmark based on control plots Estimated Vegetative stocks	Estimation by accounting both tree and non- tree biomass on land prior to the project. IPCC values can be used for vegetation types where specific info not available	AR-TOOL14 v4.2 (carbon stock in aboveground and belowground biomass of pre-project trees can be set at zero in the baseline scenario)
Project Scenario	Assess changes in Carbon stock over time	Evaluates change in Tree volume throughout the duration of the project.	
	GHG emission from Nitrogen fertilizer if applicable	GHG emission from nitrogen fertilizer accounted for 1 year.	
Area demarcation	Area-Based Approach- The spatial extent of the project boundary will encompass all the lands that are subjected to the	In terms of calculation Modelling Units are accounted.	Sample plot and sub plots

	implementation of the ARR project activity. Census-Based Approach- The relevant spatial boundary in the census-based approach will involve making a 10-metre radius buffer around the geo location of each planting unit.	MU areas normally have homogeneous characteristics in their growth patterns, silvicultural treatment and planting Date. Differentiate between Planting area and eligible planting area should be clearly defined.	
Listing Documents	Project Description, Listing Representation, NPRR, ex-ante	Preliminary Review Form, POA Design Consultation Report, Stakeholder Consultation Report, Term & Condition Document, Risks, Capacities Assessment	Accessible only once you register
Range of Methodologies available	VERRA has its own ARR Methodology (VM0047, currently under revisions)	GS has its own ARR Methodology	Doesn't have any separate methodology. It has a single document covering all details from project registration to information similar to as in a methodology and specific for ARR type of projects.
Time available for project developers to adapt to new Standard requirements and methodology updates and changes	Often not sufficient time	There is sufficient warning and time given to adapt	Still new to have revisions
Market Value of Standard	Medium	High (mainly due to importance assigned to SDGs and stakeholders)	Still new. Getting active involvement of smallholder specifically involving transition to agroforestry.

Stakeholder Consultation and Engagement	Standard requirement: The project proponent shall conduct a stakeholder consultation before implementation of project activities. Such consultations shall be done in a manner that is inclusive, culturally appropriate and respectful of local knowledge.	Stakeholder Consultation shall comprise of a minimum of two rounds of consultation including one mandatory physical meeting and one stakeholder feedback round lasting for at least two months and these consultations shall be open to anyone wishing to attend.	Very few details available for the process.
	Our opinion: Verra has just started prioritising stakeholder engagement in a big way.	Our opinion: Stakeholder engagement is not new to the GS. It is integrated in better way with the GS	
Free Prior Informed Consent (FPIC)	Yes	Yes	Yes
Global Stakeholder Consultation (GSC)	30 Days (now extended to entire project duration)	30 Days	
Start Date	Date on which activities that lead to the generation of GHG emission reductions or removals are implemented	Project start date is the earliest date on which the Project Developer has committed to expenditures related to the implementation of the project.	
Crediting period	For all AFOLU projects other than ALM projects, the initial project crediting period shall be a minimum of 20 years up to a maximum of 100 years, which may be renewed at most four times, with a total project crediting period not to exceed 100 years.	Minimum 30 years, Maximum 50 years	10 years
Longevity	At least 40 years	NA	

Risk Buffer	as per NPRT	20%	15%
Validation	Within 8 years for all AFOLU projects having ERs less than 20,000, Within 8 years for all ARR, IFM, Within 5 years for all other AFOLU having ERs more than 20,000	Project shall complete Validation (defined as the date of submission of Validation Report by the VVB) within two years of successful listing of the project.	Conducts initial validation assessment within one year of the project start
Annual Report	NA	An annual report shall be submitted for each monitoring year by end of next calendar year for which verification is not completed2. If a verification is in progress but not completed, then an Annual Report is still required by the end of calendar year.	Annual reports every year
Credit issuance	VCUs	VERs	CRUs (fPVCs, rPVCs and vPVCs) for net GHG removals
Verification	Once in 5 years	Once in 5 years, no later than 2 years after Project implementation or Design Certification, whichever is later. In case of Design Certification Renewal, it must take place no later than two years after Design Certification Renewal.	Conducted at least every three years by independent and qualified verifiers
Benefit sharing % between the project developers/ PPs and beneficiaries	No fixed % yet, upto discretion of project developers	No fixed % yet, upto discretion of project developers	At least 80% or more of the proceeds from CRU sales should accrue to participants
Renewal of Crediting period	ARR projects can have a minimum crediting period of 20 years with five times renewal i.e. upto 100 years.	Varies from project to project, beneficiaries get trainings on sustainable practices, some	

Additional Certifications	CORSIA, Article 6	CORSIA	
Cost of certification and issuance	High	High	

Filters and Parameters for Scoping and Feasibility of Areas

Information may be used as parameters for identification and scoping of projects for developing carbon projects in the state.

Scoping and feasibility (Level 1)

S. No.	Parameter	Options
	A. Project Design Filters (Carbon)	
1.	Project Type	ARR
2.	Project Scale	Small (<3,00,000 CO_2e annually) Large (>3,00,000 CO_2e annually)
3.	Project Activities (carbon)	Agroforestry/ANR/Enrichment plantations/ Plantation on community lands/Establishment of nurseries/Reduced use of synthetic fertilisers/Switch to organic fertilisers/Soil moisture conservation/ Harvesting/ Replanting/Other Silviculture practices/Any new planting technique or technology, agriculture improvement etc.
4.	Project area should not have been cleared of native ecosystems within 10 years prior to project start date	Yes/No
5.	Availability of Management Plan	Yes/No
6.	Planting Years	
7.	Species planted in project	
8.	Non-Native Species are part of project	Yes/No/NA
9.	Harvesting involved in project	Yes/No

10	If Yes, harvesting year/cycle of species	
11	Partial harvesting	Yes/No/NA
12	If Yes, intensity and timeline	
13	Planting Design	Block/Boundary/Intercrop/Roadside
14	Per hectare Abundance of each species planted	
15	Alternative Land Uses	Agriculture/Resort/Sell/Factory/ Government Acquisition
16	Any forest carbon project previously developed or under development?	Yes/No
17	Project Activities (non-carbon)	Water Conservation/Awareness Raising/ Value Chain Development/Training and Capacity Building/High Yielding Agriculture varieties/Marketing/Value Addition, etc.
18	Community Participation is part of project design	Yes/No/NA

Scoping and feasibility (Level 2)

During the scoping phase, the eligibility criteria as per the requirement of VCM will be checked which would further help in scrutinizing the selected projects. The following parameters and more suitable will be used to collect the required information and identify the potential areas for developing carbon projects in the state:

S. No.	Parameter	Description
1.	Applicability of any existing government scheme	Yes/No/NA
2.	If, yes, applicable scheme(s)	Scheme(s)
3.	Project Location	District(s), Division(s), Range(s)
4.	Geo-coordinates	
5.	KML file availability	Yes/No
6.	Project Area (ha)	
7.	Potential Project Proponent	Government Department/Local Community/ FPOs/NGO (or CBO)/ Gram Panchayat/ Corporate, etc.

S. No.	Parameter	Description
8.	Project Implementing Agency (carry out project activities)	Same as Project Proponent/Government Department/Local Community/FPOs/NGO (or CBO)/Gram Panchayat/Corporate, etc.
9.	Activity Status	Eg: Plants planted/To be planted/NA
10.	Land Ownership Status	Revenue/Forest/Common/Community/ Gram Panchayat/Individual/Lease/ Institutional
11.	Documentation to prove legal land rights	Ownership/Sale Records/Khasra-Khatauni, etc.
12.	Activity site(s) identified	Yes/No
13.	Activity site(s) type	Small patches (0.05-50 ha) Medium patches (> 50 ha) Large patches (>500 ha)
14.	Status of soils in project area	Template
15.	Is project located in a wetland area?	Yes/No
16.	Water Availability	Water Scarce/Irrigation/Rainfed
17.	Is list of villages/GPs/JFMCs/ EDCs, etc. available	Yes/No/NA
18.	Project Beneficiaries identified	Yes/No
19.	Project Beneficiaries	Farmers/SHGs/JFMCs/FPOs/BMCs/EDCs, VPs, any other community institution/NA

Stakeholder Consultation

A stakeholder consultation was conducted on 11th September 2024 in the Forest and Environment Department Office at Gangtok, Sikkim. The meeting was chaired by Secretary Mr Pradeep Kumar and was attended by several other forest department officials. Professionals from TERI and Renew who joined the consultation both physically and online, explained the department about the carbon financing project. The purpose of this workshop was to apprise the FED Sikkim about:

- Carbon financing mechanism and its application in the forestry sector
- Procedural requirements for project development
- State preparedness
- Present the findings of the study conducted so far and the way forward
- To understand the eligible interventions by FED
- Based on discussion, narrowing down/ finalizing the locations for carbon project development in Sikkim

At start, there were three technical sessions, which were explained to FED by TERI:

- Introduction to Carbon Financing in Forestry (ARR, REDD, IFM)
- Process of Project Development and State Preparedness
- Feasibility Assessment and Project Suitability

This was followed by detailed discussions on which all plantation schemes can be undertaken for the carbon project development. The department shared with TERI team that plantations have happened under MRMS scheme, CAMPA, and JICA Project. It was decided that the department will be sharing further information (plantation detail along with geo-coordinates) regarding the plantation activities. Further, TERI will evaluate those plantations and present its findings in the final report.

The agenda and the attendance sheet of the consultation are provided in the annexure I & II.

Post the workshop, TERI team with the officials from the Forest Department visited the field to assess the plantations under MRMS and CAMPA schemes. MRMS is a state scheme under which 100 plants are planted with every birth in the state. It was operationalized in 2023. Under CAMPA plantations, the plantation of oak and other native species was done in the area after the felling of the exotic bamboo species. The key points observed based on the field visit are as follows:

- The plantation under CAMPA and the Oak restoration site (*though present and excellent case study and is beneficial for the local ecosystem*) cannot be considered for carbon financing due to conditions of regulatory compliance as well as land clearing/ tree felling.
- The plantations under MRMS may be considered for carbon financing, provided they qualify the various criteria mentioned in VM0047 and VCS Standard.

Remote Sensing Analysis

LULC Change Mapping

Land use and land cover (LULC) is a broad framework that integrates terrain features and landscape activities, allowing for an organized approach to examine and analyse changes through time. Comparison and analysis of LULC of different periods is crucial in understanding the spatio-temporal changes in the Landscape.

The land use land cover maps (2009, 2013, 2017, 2021, 2023) of a study area have been generated using Landsat 5 and 8 at a 30 m resolution. Around 8 land use/land cover (LULC) categories such as Snow, Agriculture, Forest Green, Barren & Open Land, Settlement and Waterbody have been identified.

The following pie chart offers insight into the area statistics for the study area for the years 2013 and 2023:

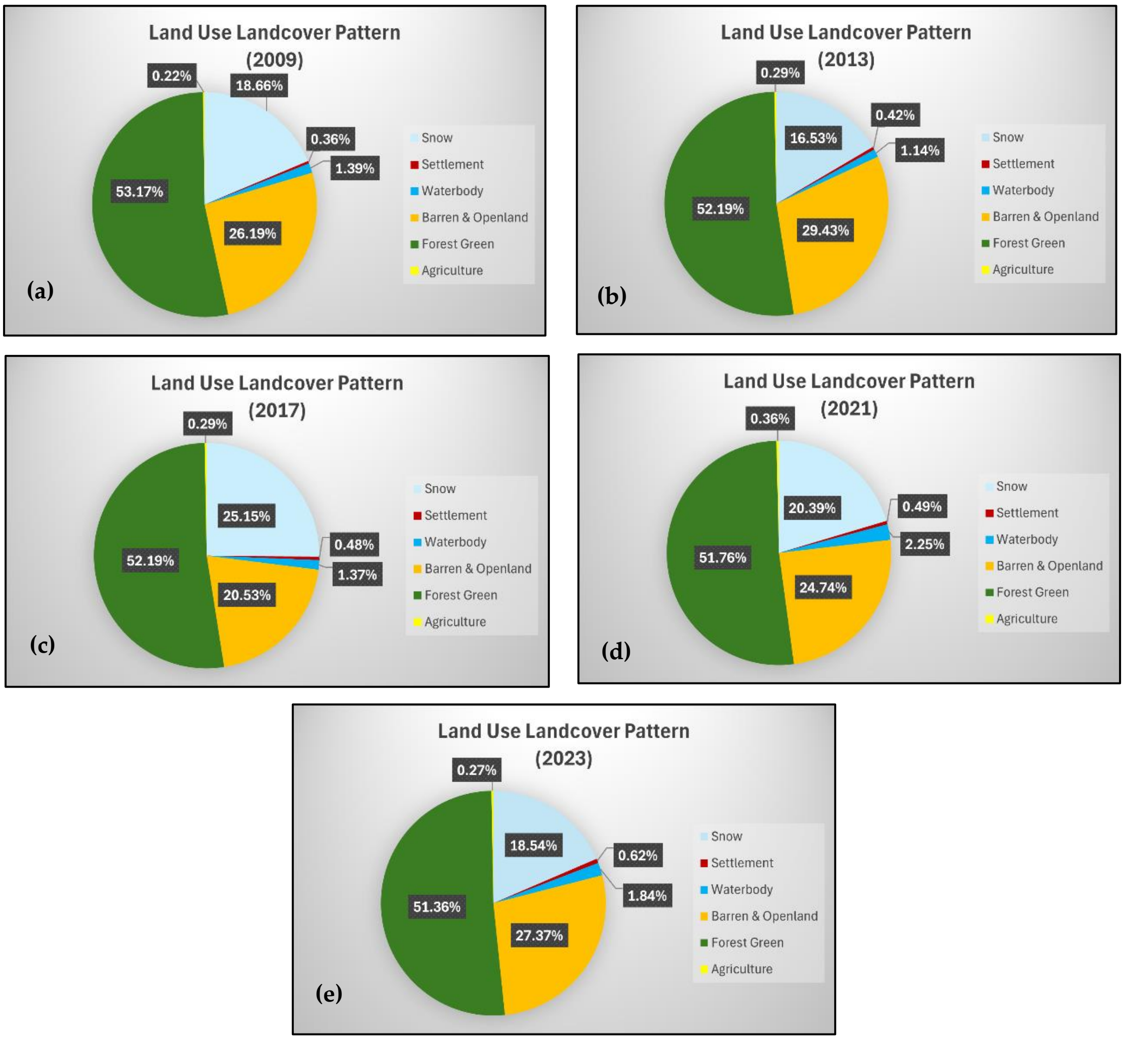


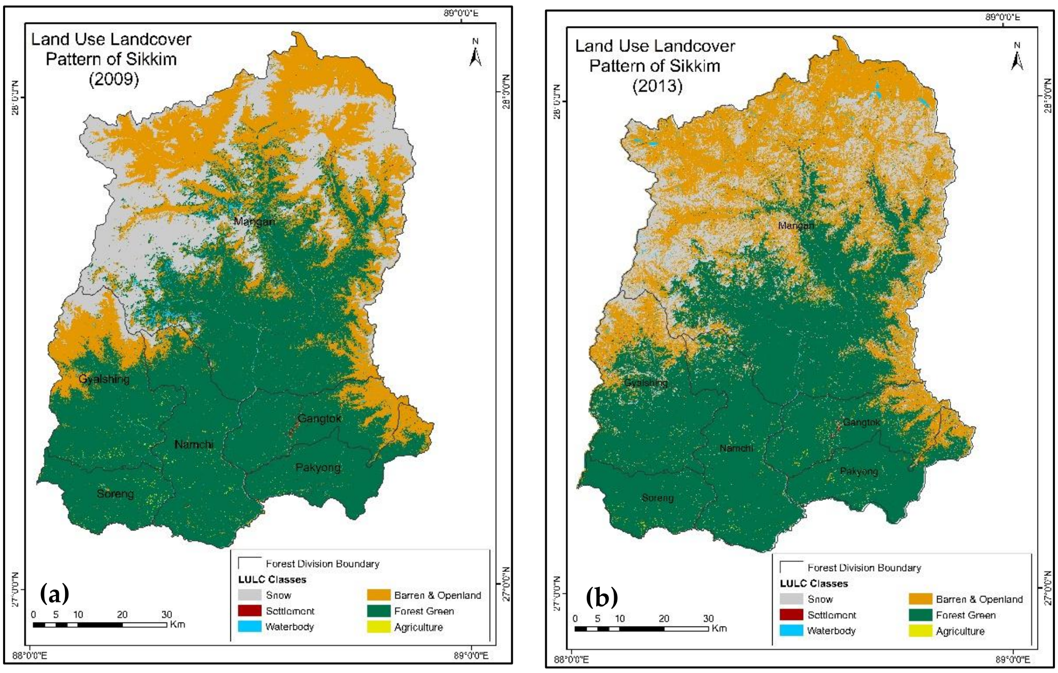
Figure 7 Pie chart of (a) 2009 LULC, (b) 2013 LULC, (c) 2017 LULC, (d) 2021 LULC, (e) 2023 LULC

Statistical analysis of the study area covering the entire state of Sikkim for the years 2009 and 2023 reveals slight changes in land use patterns. The Forest area has notably decreased by approximately 125 square kilometers over the 14-year period. In contrast, categories such as settlement have shown notable increases (18.17 sq. km). Conversely, Barren and Open Land have increased by about 85.17 square kilometers.

S. No	Class	2009	2013	2017	2021	2023
		AREA (in SQ km)	AREA (in SQ km)	AREA (in SQ km)	AREA (in SQ km)	AREA (in SQ km)
1	Snow	1323.89	1173.85	1778.19	1441.21	1315.78
2	Settlement	25.62	30.03	33.86	34.78	43.79
3	Waterbody	98.94	80.63	96.68	159.06	130.58
4	Barren & Open land	1857.81	2089.65	1451.49	1748.54	1942.98
5	Forest Green	3771.50	3706.58	3689.68	3658.73	3645.70
6	Agriculture	15.96	20.79	20.28	25.63	19.51
7	Total	7101.53	7101.54	7101.59	7101.56	7101.55

Table 7 LULC Statistics

The area statistics (Table 7) and classification trends have been also verified with reliable sources such as Bhuvan, (Indian State of Forest Report), and ESA (European Space Agency). This multi-source validation ensures reliability and accuracy. Below is the visual representation illustrating the land use and land cover patterns (Fig.8):



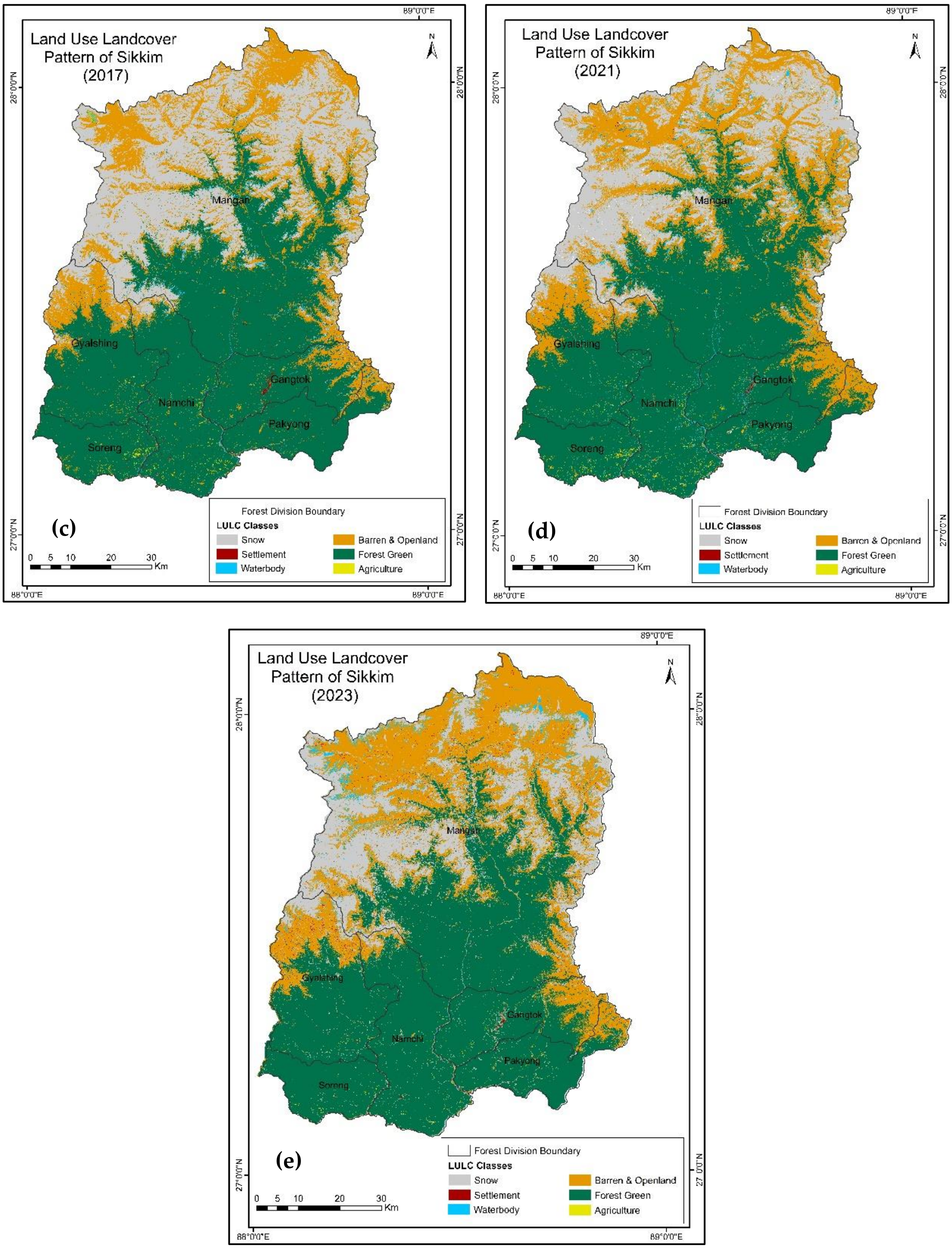


Figure 8 LULC Maps for (a) 2009, (b) 2023, (c) 2017, (d) 2021, (e) 2023; Prepared by TERI

Based on visual interpretation, Snow cover is primarily concentrated in Mangan District, which is also the largest district of Sikkim. The rest of the districts are majorly covered with forest green. Built-up areas are concentrated in a small patch, a major patch of settlement is in Gangtok. Additionally, Agricultural land is found in small, scattered patches in all the districts.

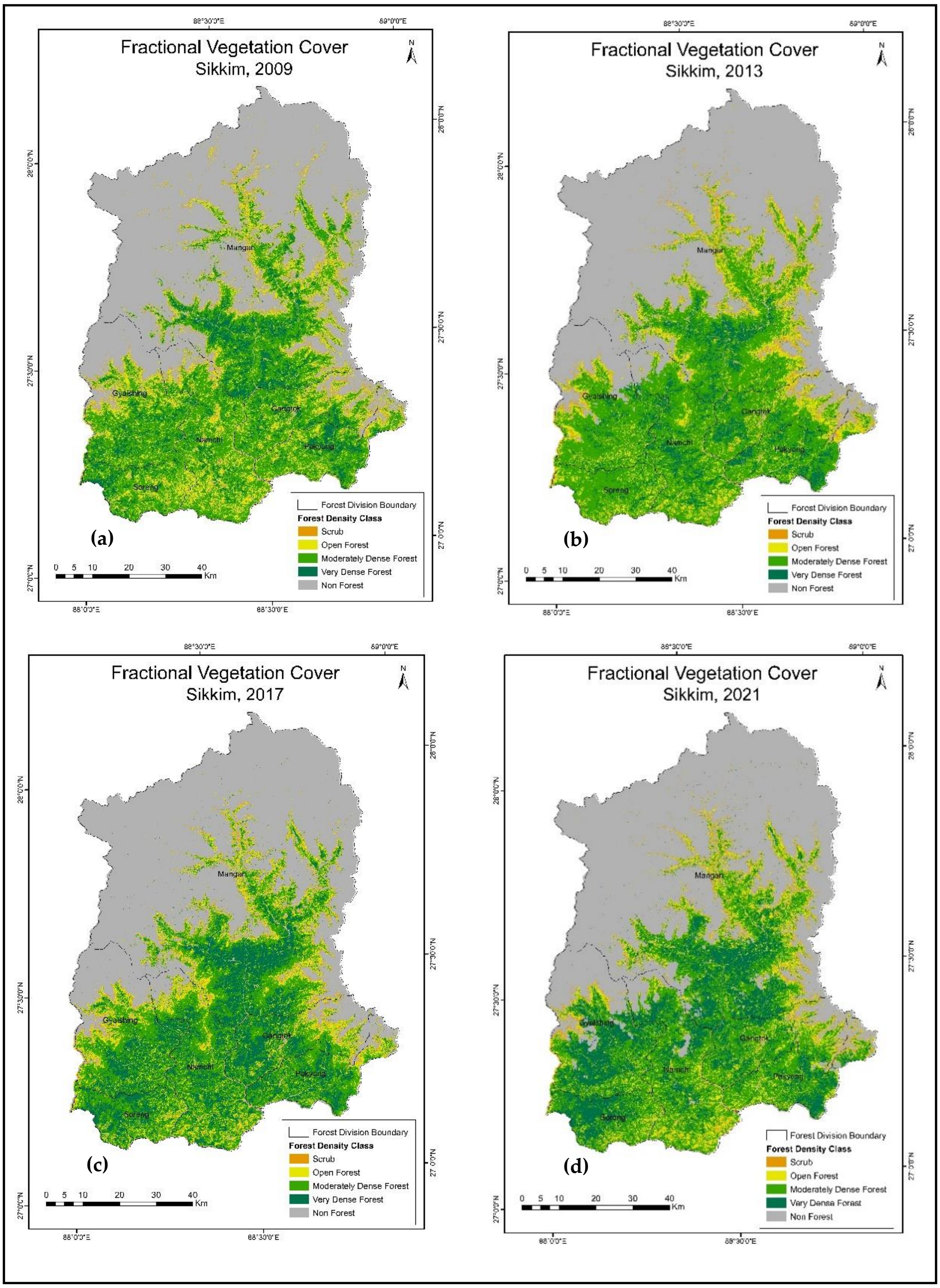
Forest Density Change Mapping

Fractional Vegetation Cover (FVC):

According to the spatio-temporal visualization of vegetation cover in the study area, a significant portion is forest. The northern regions, however, are predominantly non-forest. When examined alongside the Land Use Land Cover (LULC) data, it becomes evident that the northern non-forest area primarily consists of barren land and permanent snow.

The Forest Vegetation Cover (FVC) that defined as the projected percentage of the total study area that is vegetated [18]. It incorporated 4 forest classes scrubland, open forest, moderately dense forest, and very dense forest. As per visual interpretation, most of the forest cover is concentrated in the central part of the study area.

In 2009, the central southern region was predominantly covered by very dense forest (VDF), while the area surrounding the VDF had substantial areas of open and moderately dense forest (OF & MDF). However, in the following years—2013, 2017, 2021, and 2023—the very dense forest in the southern region gradually transitioned to moderately dense forest. In the central region, disturbances became more evident, with moderately dense forests increasingly converted to open forest. The following maps provide an insight into the Fractional Vegetation Cover in the ROI (Fig 9):


Fractional Vegetation Cover
Sikkim, 2009
Mangan
Gyalshing
Gangtok
Namchi
Pakyong
Soreng
Forest Division Boundary
Forest Density Class
Scrub
Open Forest
Moderately Dense Forest
Very Dense Forest
Non Forest
(a)
Fractional Vegetation Cover
Sikkim, 2013
(b)
Fractional Vegetation Cover
Sikkim, 2017
(c)
Fractional Vegetation Cover
Sikkim, 2021
(d)
Km

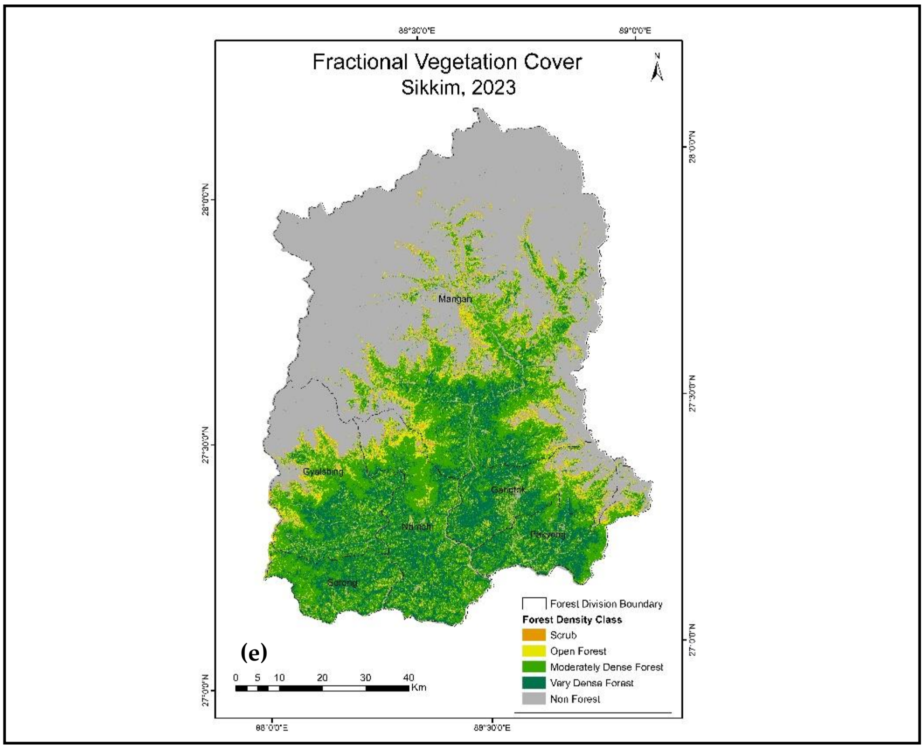
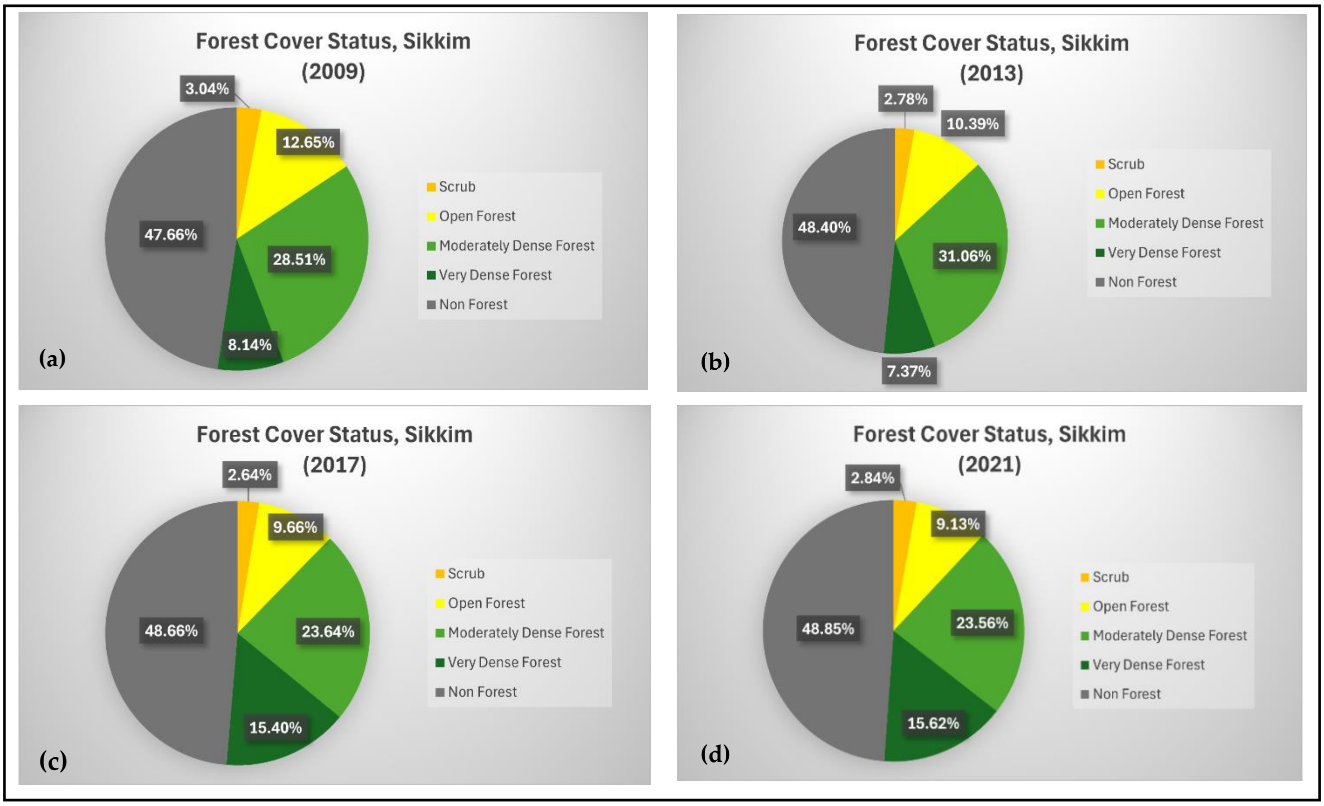


Figure 9 FVC Maps (a)2009, (b) 2013, (c) 2017, (d) 2021, (e) 2023 for Long-term analysis; Prepared by TERI

The following Pie chart (Fig. 10) and Table offer insight into the area statistics for Sikkim for the years 2009, 2013, 2017, 2021, and 2023:



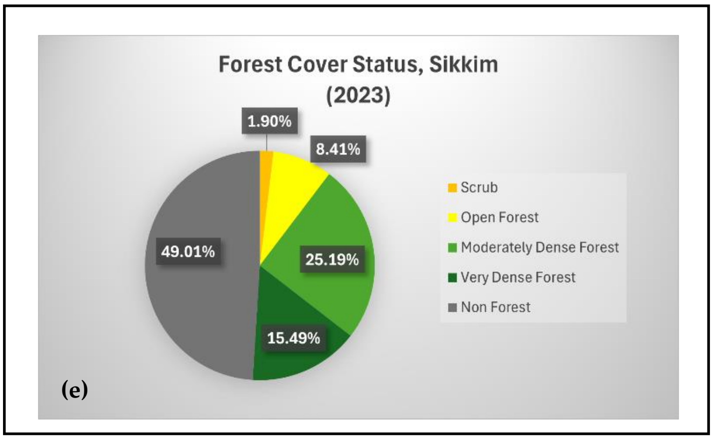


Figure 10 Pie charts (a) 2009, (b) 2013, (c) 2017, (d) 2021, (e) 2023 of FVC Status

Value	Class	2009	2013	2017	2021	2023
		Area (In Sq. Km)	Area (In Sq. Km)	Area (In Sq. Km)	Area (In Sq. Km)	Area (In Sq. Km)
1	**Scrub**	215.93	197.42	187.22	201.82	135.26
2	**Open Forest**	898.69	738.2	686.49	648.7	597.2
3	**Moderately Dense Forest**	2025.48	2206.84	1679.57	1674.03	1789.57
4	**Very Dense Forest**	578.07	523.24	1093.91	1109.36	1100.28
5	**Non-Forest**	3385.84	3438.31	3456.81	3470.1	3481.7
Total		**7104.01**	**7104.01**	**7104.01**	**7104.01**	**7104.01**

Table 8 FVC Analysis Statistics

An analysis of forest cover from 2009 to 2023 (table 8) reveals a decrease of 95.86 square kilometers in the total forest regions of Sikkim. However, from 2009 to 2023, the trend for very dense forests shows a significant increase of about 522 square kilometers. In contrast, moderately dense forests have experienced a significant decrease, amounting to approximately 235.91 square kilometers over the 15-year period. Open forests, which showed a decreasing trend from 2009 onward, till 2023. Overall, Sikkim has experienced a notable reduction in total forest area as well as the quality of the forest.

Successive Fractional Vegetation Cover (FVC):

The Linear Spectral Un-Mixing (LSU) model has been employed to estimate the Fractional Vegetation Cover (FVC) over four consecutive years (2020-2023). This analysis has been used to assess a scenario of successive land degradation, characterized by the continuous decline in land quality over time due to factors such as soil erosion, and unsustainable agricultural practices. This progressive degradation adversely impacts land productivity, biodiversity, and ecosystem services.

The forthcoming map presents comprehensive data on the Fractional Vegetation Cover of Sikkim for the successive years 2020, 2021, 2022, and 2023 (Fig 11).

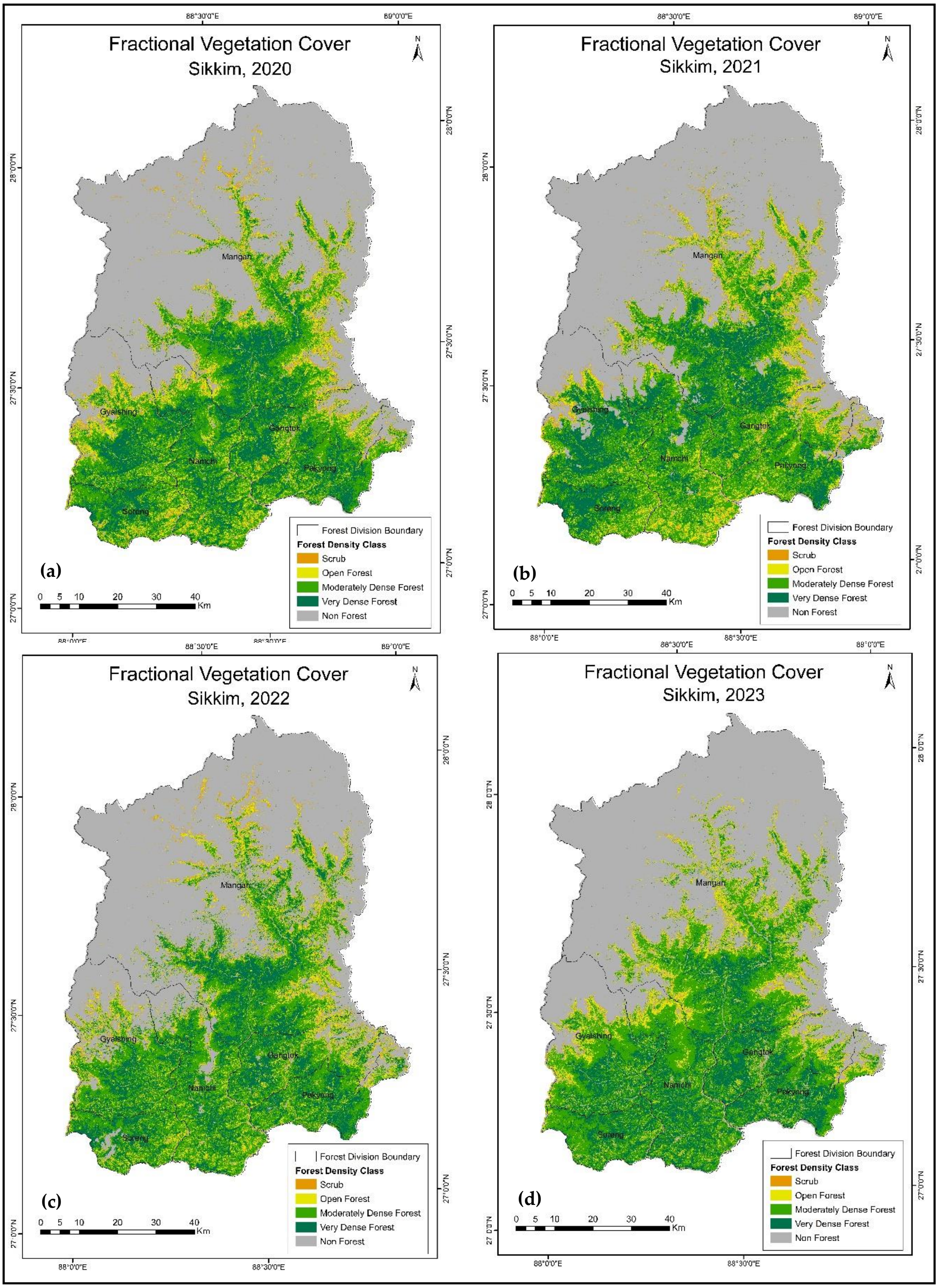


Figure 11 Maps of FVC Analysis for successive years (a) 2020, (b) 2021, (c) 2022, (d) 2023; Prepared by TERI

Value	Class	2020	2021	2022	2023
		Area (In Sq Km)	Area (In Sq Km)	Area (In Sq Km)	Area (In Sq Km)
1	Scrub	213.8877	201.82	214.04	135.26
2	Open Forest	661.2471	648.70	646.45	597.20
3	Moderately Dense Forest	1661.3937	1674.03	1664.59	1789.57
4	Very Dense Forest	1107.5301	1109.36	1102.79	1100.28
5	Non-Forest	3459.95	3470.10	3475.39	3481.70
Total		**7104.01**	**7104.01**	**7103.27**	**7104.01**

Table 9 FVC Successive Years Statistics

The following pie chart offers insight into the area statistics of Sikkim for the years 2020, 2021, 2022, and 2023 (Fig 12).

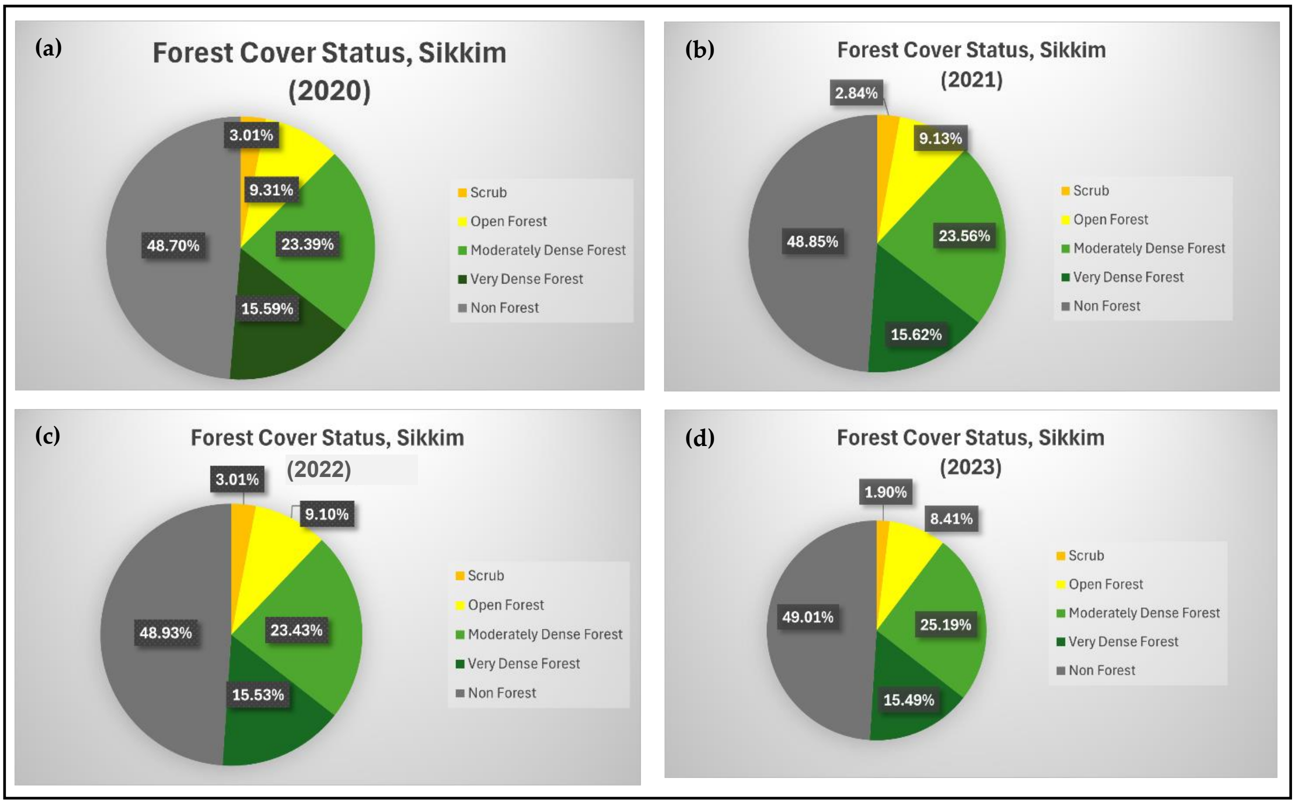


Figure 12 FVC pie charts for successive analysis (a) 2020, (b) 2021, (c) 2022, (d) 2023

The Analysis of forest cover between 2020 and 2023 indicates a decrease of approximately 7 sq. km in very dense forests. In contrast, moderately dense forests expanded by about 128 sq. km over the same period. Sikkim, however, saw a slight overall decline in forest cover, losing around 21.75 sq. km.

Change Matrix for historical forest density change detection

A change matrix illustrates the transformation of categories over time. The matrices provided below depict shifts in fractional vegetation cover (FVC) for the periods 2009-2013, 2013-2017, 2017-2021, and 2021-2023 within the study area (see Table 10-13). The diagonal cells of the table represent areas where no changes occurred, while the other cells indicate regions of transformation. These matrices are instrumental in tracking both stability and change in FVC across multiple time intervals.

FVC Change Matrix (2009-2013)							
	FVC Change (Area in Sq. Km)	**2013**					
		Non-Forest	**Scrub**	**Open Forest**	**Moderately Dense Forest**	**Very Dense Forest**	**Grand Total**
2009	**Non-Forest**	**3122.99**	69.37	113.99	64.76	13.32	3384.42
	Scrub	94.64	**26.54**	48.71	39.70	6.33	215.91
	Open Forest	141.26	71.83	**276.83**	351.23	57.48	898.63
	Moderately Dense Forest	69.27	27.43	280.36	**1362.52**	285.77	2025.36
	Very Dense Forest	8.75	2.21	18.20	388.54	**160.33**	578.03
	Grand Total	3436.91	197.38	738.09	2206.74	523.23	7102.35

Table 10 FVC Change Matrix (2009-2013)

In the study area, between 2009 and 2013, a total of 160.33 sq. km of Very Dense Forest (VDF) remained unchanged. During this period, 388.54 sq. km of VDF transitioned to Moderately Dense Forest, while 18.20 sq. km shifted from VDF to Open Forest. A smaller portion, 2.21 sq. km, converted to Scrub, and 8.75 sq. km transitioned from VDF to Non-Forest.

Similarly, during the same period, 285.77 sq. km of Moderately Dense Forest was transformed into Very Dense Forest. Additionally, 57.48 sq. km changed from Open Forest to VDF, while 6.33 sq. km transitioned from Scrub to VDF. Moreover, 13.32 sq. km of non-forest was converted into VDF over the four-year period.

FVC Change Matrix (2013-2017)							
	FVC Change (Area in Sq. Km)	2017					
		Non-Forest	Scrub	Open Forest	Moderately Dense Forest	Very Dense Forest	Grand Total
2013	Non-Forest	**3257.64**	50.53	78.56	42.06	9.51	3438.31
	Scrub	88.08	**46.59**	51.15	10.22	1.39	197.42
	Open Forest	79.20	68.82	**351.57**	223.86	14.75	738.20
	Moderately Dense Forest	24.55	19.15	192.28	**1260.71**	710.15	2206.84
	Very Dense Forest	7.34	2.12	12.94	142.73	**358.11**	523.24
	Grand Total	3456.81	187.22	686.49	1679.57	1093.91	7104.01

Table 11 FVC Change Matrix (2013-2017)

Between 2013 and 2017 in the study area, a total of 358.11 sq. km of Very Dense Forest (VDF) remained unchanged (in bold). Over this period, 142.73 sq. km of VDF transitioned to Moderately Dense Forest, while 12.94 sq. km shifted to Open Forest. A smaller area of 2.12 sq. km converted to Scrub, and 7.34 sq. km transitioned from VDF to Non-Forest.

Additionally, during this time frame, 710.15 sq. km of Moderately Dense Forest was converted to Very Dense Forest. A further 14.75 sq. km transitioned from Open Forest to VDF, while 1.39 sq. km shifted from Scrub to VDF. Moreover, 9.51 sq. km of non-forest was transformed into Very Dense Forest during this four-year period.

FVC Change Matrix (2017-2021)							
	FVC Change (Area in Sq. Km)	2021					
		Non-Forest	Scrub	Open Forest	Moderately Dense Forest	Very Dense Forest	Grand Total
2017	Non-Forest	**3227.49**	97.45	88.36	32.23	11.28	3456.81
	Scrub	50.08	**40.99**	67.49	24.39	4.27	187.22
	Open Forest	99.91	44.73	**279.73**	225.65	36.47	686.49
	Moderately Dense Forest	79.04	15.14	190.00	**969.97**	425.43	1679.57
	Very Dense Forest	13.58	3.51	23.13	421.78	**631.91**	1093.91
	Grand Total	3470.10	201.82	648.70	1674.03	1109.36	7104.01

Table 12 FVC Change Matrix (2017-2021)

From 2017 to 2021, within the study area, a total of 631.91 sq. km of Very Dense Forest (VDF) remained unchanged (in bold). During this period, 421.78 sq. km of VDF transitioned to Moderately Dense Forest, while 23.13 sq. km shifted to Open Forest. A minor area of 3.51 sq. km converted to Scrub, and 13.58 sq. km transitioned from VDF to Non-Forest.
Similarly, during this period, 425.43 sq. km of Moderately Dense Forest was converted to Very Dense Forest. Additionally, 36.47 sq. km shifted from Open Forest to VDF, while 4.27 sq. km transitioned from Scrub to VDF. Furthermore, 11.28 sq. km of non-Forest was restored to Very Dense Forest over these four years.

FVC Change Matrix (2021-2023)							
	FVC Change (Area in Sq. Km)	**2023**					
		Non-Forest	**Scrub**	**Open Forest**	**Moderately Dense Forest**	**Very Dense Forest**	**Grand Total**
2021	**Non-Forest**	**3194.46**	38.29	113.47	104.87	19.00	3470.10
	Scrub	124.86	**18.54**	34.96	19.63	3.83	201.82
	Open Forest	114.75	58.08	**224.93**	222.79	28.16	648.70
	Moderately Dense Forest	34.93	17.85	199.49	**960.16**	461.58	1674.03
	Very Dense Forest	12.70	2.50	24.35	482.11	**587.71**	1109.36
	Grand Total	3481.70	135.26	597.20	1789.57	1100.28	7104.01

Table 13 FVC Change Matrix (2021-2023)

Between 2021 and 2023, in the study area, 587.71 sq. km of Very Dense Forest (VDF) remained unchanged (in bold). During this period, 482.11 sq. km of VDF transitioned to Moderately Dense Forest, while 24.35 sq. km shifted to Open Forest. A minimal area of 2.50 sq. km converted to Scrub, and 12.70 sq. km transitioned from VDF to Non-Forest.

Additionally, from 2021 to 2023, 461.58 sq. km of Moderately Dense Forest was restored to Very Dense Forest. The area of Open Forest that converted to VDF was 28.16 sq. km, while 3.83 sq. km shifted from Scrub to VDF. Furthermore, 19 sq. km of non-forest was reclaimed as Very Dense Forest during this period.

Change Matrix Analysis for Successive Years

The continuous degradation of forested areas can ultimately result in deforestation. To monitor these changes effectively, remote sensing techniques have been utilized for short-term observation (Hurni, 1996). For a detailed quantification of land transitions, successive land transition matrices have been integrated into the analysis.
Between 2020 and 2021, the study area saw 657.22 sq. km of Very Dense Forest (VDF) remain unchanged. During this time, 396.15 sq. km of VDF changed to Moderately Dense

Forest, while 27.69 sq. km shifted to Open Forest. Additionally, 4.61 sq. km of VDF converted to Scrub, and 21.02 sq. km became non-Forest. Conversely, 398.52 sq. km of Moderately Dense Forest changed to VDF, 30.97 sq. km of Open Forest was converted to VDF, and 5.22 sq. km of Scrub turned into VDF. Furthermore, 17.44 sq. km of non-Forest was transformed into VDF over the year.

FVC Change Matrix (2020-2021)							
	FVC Change (Area in Sq Km)	2021					
		Non-Forest	Scrub	Open Forest	Moderately Dense Forest	Very Dense Forest	Grand Total
2020	Non-Forest	3200.94	88.20	101.56	55.93	17.44	3464.06
	Scrub	76.40	46.29	61.65	23.74	5.22	213.30
	Open Forest	94.01	46.82	279.92	208.51	30.97	660.22
	Moderately Dense Forest	77.73	15.90	177.89	989.70	398.52	1659.74
	Very Dense Forest	21.02	4.61	27.69	396.15	657.22	1106.69
	Grand Total	3470.10	201.82	648.70	1674.03	1109.36	7104.01

Table 14 FVC Change Matrix (2020-2021)

Between 2021 and 2022, the study area recorded 605.51 sq. km of Very Dense Forest (VDF) remaining unchanged. During this interval, 392.59 sq. km of VDF transitioned to Moderately Dense Forest, while 43.09 sq. km shifted to Open Forest. Additionally, 10.40 sq. km of VDF was converted to Scrub, and 57.71 sq. km transitioned to non-Forest. Conversely, 416 sq. km of Moderately Dense Forest was converted to VDF, 41.14 sq. km of Open Forest changed to VDF, and 7.54 sq. km of Scrub was transformed into VDF. Furthermore, 32.20 sq. km of non-forest was converted into VDF during this period.

FVC Change Matrix (2021-2022)							
	FVC Change (Area in Sq. Km)	2022					
		Non-Forest	Scrub	Open Forest	Moderately Dense Forest	Very Dense Forest	Grand Total
2021	Non-Forest	3080.48	106.41	151.79	97.09	32.20	3467.98
	Scrub	76.22	28.57	59.09	30.37	7.54	201.78
	Open Forest	128.18	37.43	215.88	225.99	41.14	648.61
	Moderately Dense Forest	131.55	31.20	176.52	918.38	416.31	1673.96
	Very Dense Forest	57.71	10.40	43.09	392.59	605.51	1109.30
	Grand Total	3474.13	214.00	646.38	1664.41	1102.70	7101.62

Table 15 FVC Change Matrix (2021-2022)

Between 2022 and 2023, the study area saw 703.82 sq. km of Very Dense Forest (VDF) remain unchanged. During this period, 336.88 sq. km of VDF transitioned to Moderately Dense Forest, while 32.78 sq. km shifted to Open Forest. Additionally, 5.05 sq. km of VDF was converted to Scrub, and 24.16 sq. km transitioned to non-Forest. Conversely, 347.67 sq. km of Moderately Dense Forest was transformed into VDF, 18.71 sq. km of Open Forest was converted to VDF, and 3.41 sq. km of Scrub turned into VDF. Furthermore, 26.63 sq. km of non-forest was converted into VDF during this timeframe.

FVC Change Matrix (2022-2023)							
	FVC Change (Area in Sq Km)	2023					
		Non-Forest	Scrub	Open Forest	Moderately Dense Forest	Very Dense Forest	Grand Total
2022	Non-Forest	3062.44	52.29	177.61	155.16	26.63	3474.13
	Scrub	129.21	10.90	35.60	34.88	3.41	214.00
	Open Forest	188.34	44.43	177.08	217.83	18.71	646.38
	Moderately Dense Forest	75.36	22.57	174.07	1044.75	347.67	1664.41
	Very Dense Forest	24.16	5.05	32.78	336.88	703.82	1102.70
	Grand Total	3479.50	135.24	597.14	1789.50	1100.24	7101.62

Table 16 FVC Change Matrix (2022-2023)

Forest Degradation Analysis

Forest density change refers to variations in the concentration of trees and vegetation within a forest over time. It is often measured in terms of tree biomass, canopy cover, or the number of trees per unit area (such as hectares). Changes in forest density can be influenced by factors such as deforestation, afforestation, natural disturbances (e.g., wildfires, pests), climate change, or forest management practices. These changes can have significant ecological impacts, affecting biodiversity, carbon storage, and local climates (Houghton, 2003; Pan et al., 2011). Analysing forest density change is crucial for monitoring biodiversity, carbon sequestration, and ecosystem health. It helps in understanding the impacts of deforestation, land-use practices, and climate change on forests, informing sustainable management and conservation efforts. Additionally, it aids in preserving water resources, soil quality, and the livelihoods of communities dependent on forests.

The change in the forest density of Sikkim has been documented in the form of maps and matrices for the last 15 years.

Long-term Degradation

Based on the visual representation of forest density changes between 2009 and 2013 (Figure 13), there is a notable trend of significant deforestation and degradation, these patches are scattered all over the region of the study area. The Districts of Gyalshing, Mangan, Gangtok, and Pakyong have higher degradation and deforestation than the other 3 districts. Namchi District has the lowest amount of degradation and deforestation. Deforestation can be noticed on the fringes of the forest, especially in the northern region. Afforestation and Enhancement is less than Deforestation and Degradation.

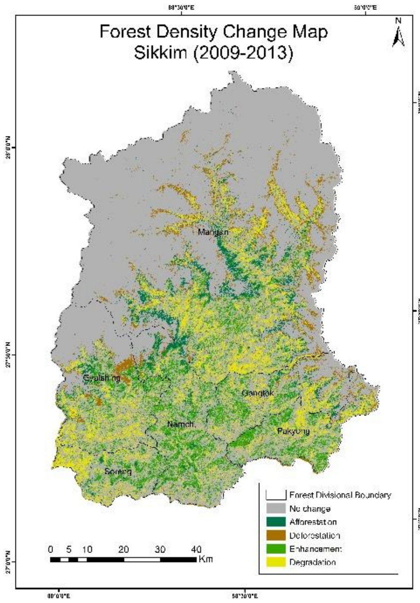


Figure 13 Forest density change map for 2009-13; Prepared by TERI

The visual representation of forest density changes from 2013 to 2017 (Figure 14) presents a contrasting narrative. During this period, the Degradation in Namchi has increased. Notably, the condition of forest cover has improved in Gangtok and Gyalshing. It can also be seen that the patches are less scattered in this time period. The enhancement and afforestation patches have increased prominently.

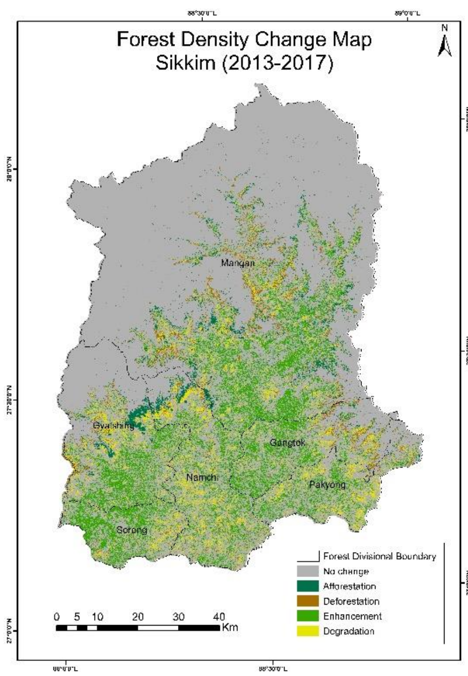


Figure 14 Forest density change map for 2013-17; Prepared by TERI

From 2017 to 2021 (Figure 15), the area under deforestation has increased considerably. During this period, the areas affected by degradation and enhancement remained nearly equal. Similarly, the areas under afforestation and deforestation were also nearly balanced. Significant deforestation patches can be seen in Gyalshing, Namchi, and Mangan.

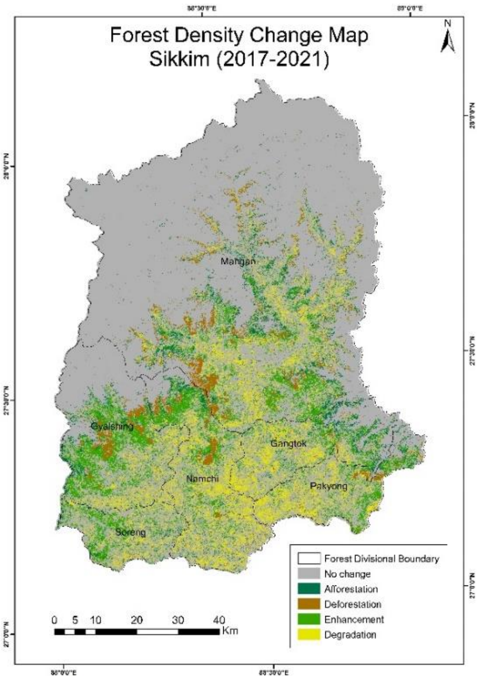


Figure 15 Forest density change map for 2017-21; Prepared by TERI

From 2021 to 2023 (Figure 16), the extent of Degradation, Afforestation, and Enhancement have increased while the extent of Deforestation has decreased.

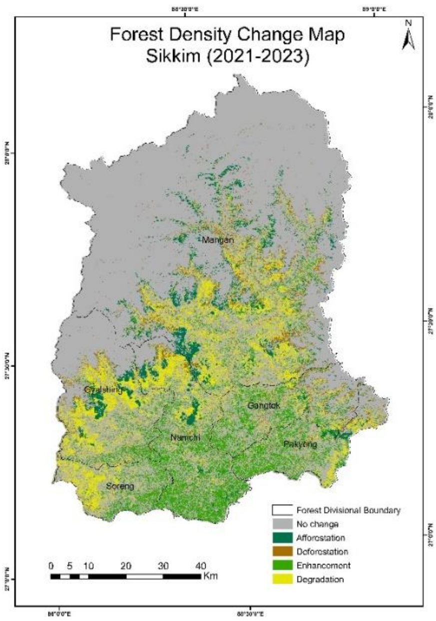


Figure 16 Forest density change map for 2021-23; Prepared by TERI

Sikkim FVC Long-term trend					
Value	FVC Degradation	2009 - 2013	2013 - 2017	2017 - 2021	2021 - 2023
		Area (in SQ km)	Area (in SQ km)	Area (in SQ km)	Area (in SQ km)
1	No Change	5113.22	5413.23	5297.62	5148.95
2	Afforestation	286.80	192.89	228.03	295.77
3	Deforestation	320.75	201.19	255.91	240.81
4	Enhancement	694.48	948.76	687.55	712.53
5	Degradation	687.10	347.95	634.91	705.95

Table 17 Sikkim FVC Long-term trend

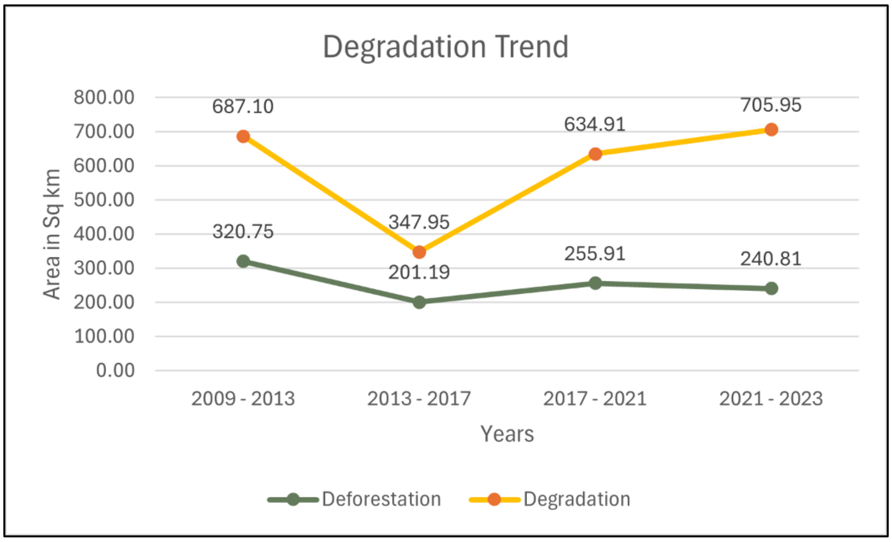


Figure 17 Degradation Trend (2009-2023)

An analysis of the overall forest density change from 2009 to 2023 reveals a gradual increase in degradation (18.85 sq. km) and a slight decline in deforestation (79.94 sq. km), particularly after 2017. This trend indicates that over the past seven years, the state has experienced ongoing degradation and deforestation.

Successive Degradation

Based on the visual representation of forest density changes between 2020 and 2023 (Fig 18), these patches are scattered all over the region of the study area. The Districts of Gyalshing, Namchi, Gangtok, and Pakyong have higher degradation and deforestation than the other districts. Deforestation can be noticed on the fringes of the forest, especially in the northern region. Afforestation and Enhancement are more than Deforestation and Degradation.

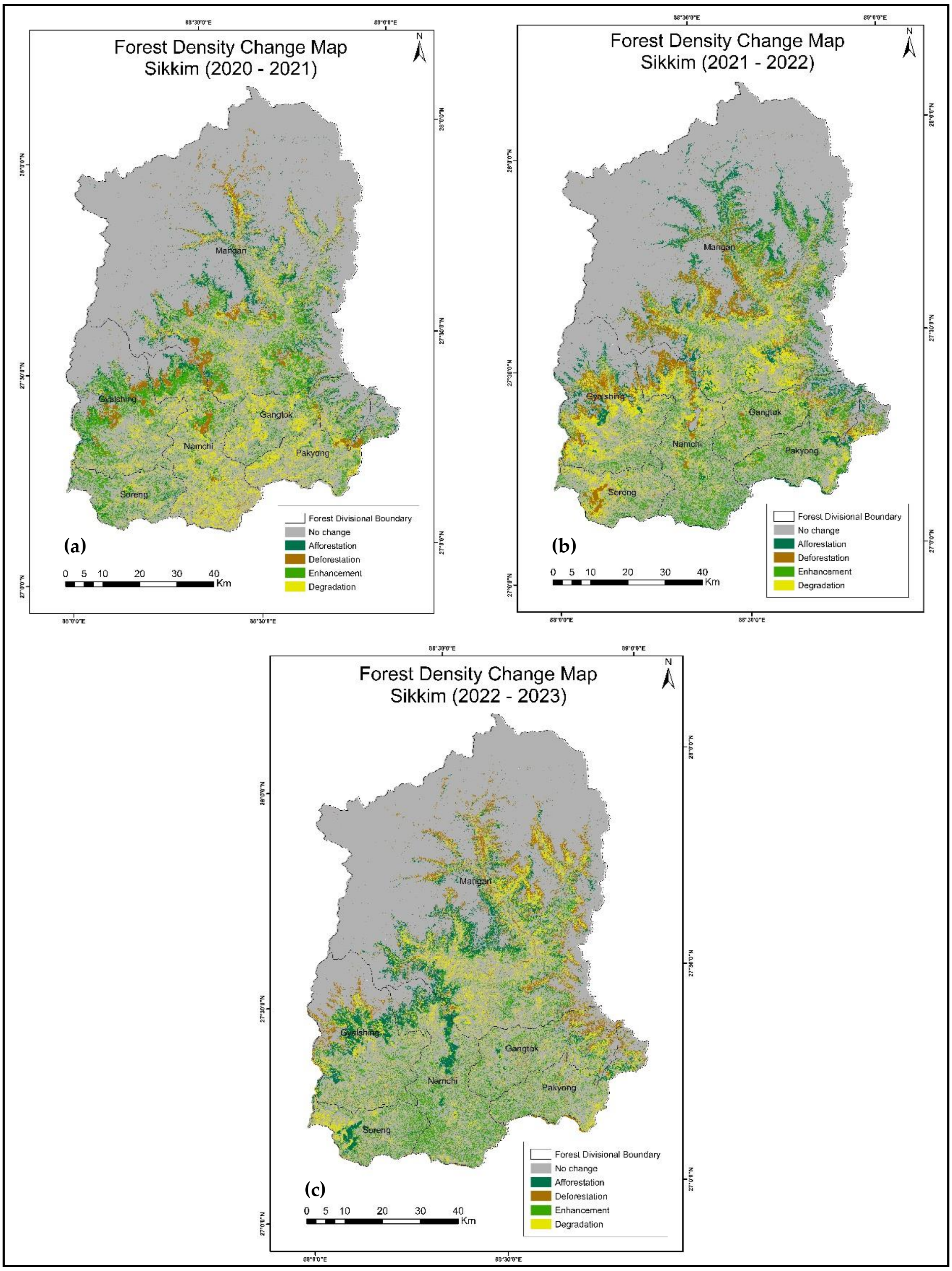


Figure 18 Forest Density Change Map for (a) 2020-21, (b) 2021-22, (c) 2022-23; Prepared by TERI

An analysis of the overall forest density change from 2020 to 2023 reveals a gradual decrease in degradation (58 sq. km) and a slight increase in deforestation (98.92 sq. km), particularly after 2017.

Sikkim FVC Successive years trend				
Value	FVC Degradation	2020-2021	2021-2022	2022 - 2023
		Area (in SQ km)	Area (in SQ km)	Area (in SQ km)
1	No Change	5338.67	5031.44	5180.49
2	Afforestation	265.53	378.08	433.30
3	Deforestation	260.08	396.46	359.91
4	Enhancement	637.99	683.44	584.20
5	Degradation	601.73	612.20	543.73

Table 18 Sikkim FVC Successive years trend

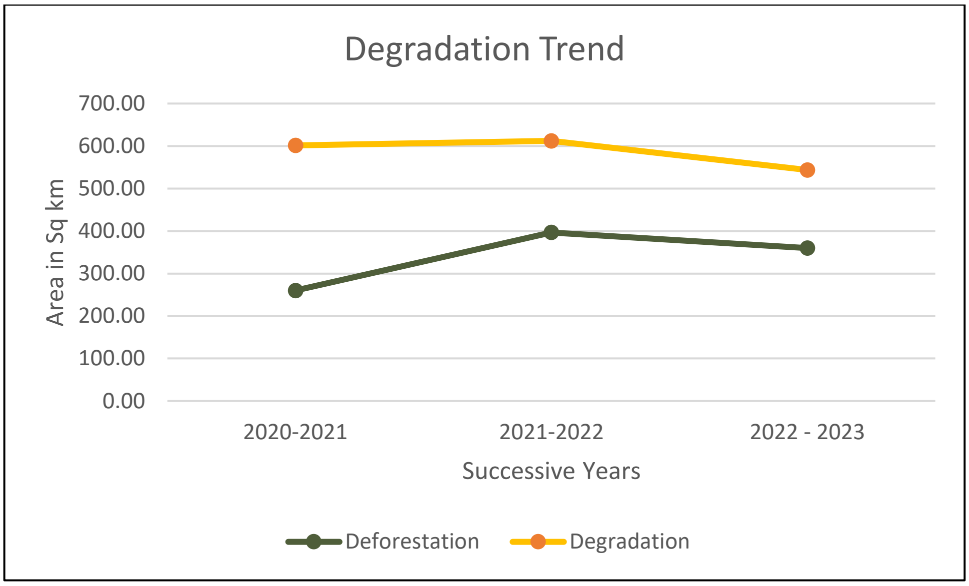


Figure 19 Degradation trend for 2020-23

Delineation of Project Boundary

The Remote Sensing and GIS-based assessment for potential ARR sites in Sikkim identified non-forested and degraded lands that remained unchanged for at least a decade (2013-2023). Through LULC change detection, areas persisting as barren or degraded were delineated as high-priority sites for ARR interventions. The analysis included evaluation of existing plantations under various government schemes such as Green India Mission (GIM) and Compensatory Afforestation schemes to determine their potential for carbon finance inclusion. Supervised classification methods, including Support Vector Machines and Random Forest, were applied to analyze satellite imagery, ensuring precise identification of non-forest persistence. Also, a comparison with high-resolution data validated the accuracy of site selection and classification.

For REDD/REDD+, a long-term forest degradation assessment (2009-2023) was conducted using FVC analysis. The study highlighted areas experiencing sustained loss of canopy density, making them suitable for REDD/REDD+ interventions. A continuous degradation map was generated to identify locations experiencing short-term, consecutive degradation trends. These findings were overlaid with historical forest change layers to pinpoint permanent degradation zones.

The study also quantified major drivers of degradation, such as fire incidents, population expansion, and agricultural encroachment, through historical LULC transitions and GIS-based analysis. Anthropogenic influences, including firewood extraction and unregulated grazing, were mapped using MODIS fire data and high-resolution settlement growth analysis. Fire vulnerability zones were identified using a Fire Point Intensity (FPI) model, while human settlement expansion within forest fringes was analyzed through GHSL-derived population distribution maps. This spatio-temporal assessment provided a detailed quantification of the relative contribution of each driver to forest degradation. Finally, a comparative assessment with high-resolution satellite data further refined LULC and FVC maps, enhancing the accuracy of forest degradation classification and site selection for potential carbon finance interventions.

1. Assessment of Potential Sites for ARR

The delineation of project boundaries for ARR sites is based on the LULC as well as forest cover. As per the guidelines of ARR methodology, the area for the potential site of project should either be a part of agriculture or barren. The areas that have transitioned from agriculture to barren or barren to agriculture in the past 10 years can also be considered. For the state of Sikkim, the land that has remained barren for the past years cannot be taken as potential sites as here majority of that land lies under high altitude zones and might not have the potential to generate credits through ARR activities.

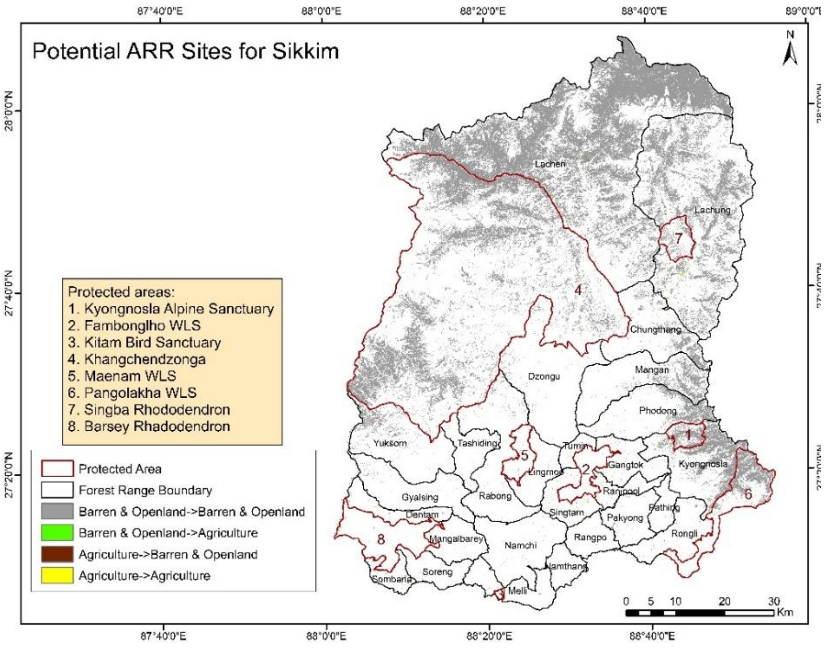


Figure 20 Potential ARR Sites for Sikkim; Prepared by TERI

While analyzing the status of forest cover, area with less than 15% pre-existing standing biomass cover is considered for potential sites (*justification provided in Annexure-III*). Here, open forest and scrub have been taken along with the transition of land between them.

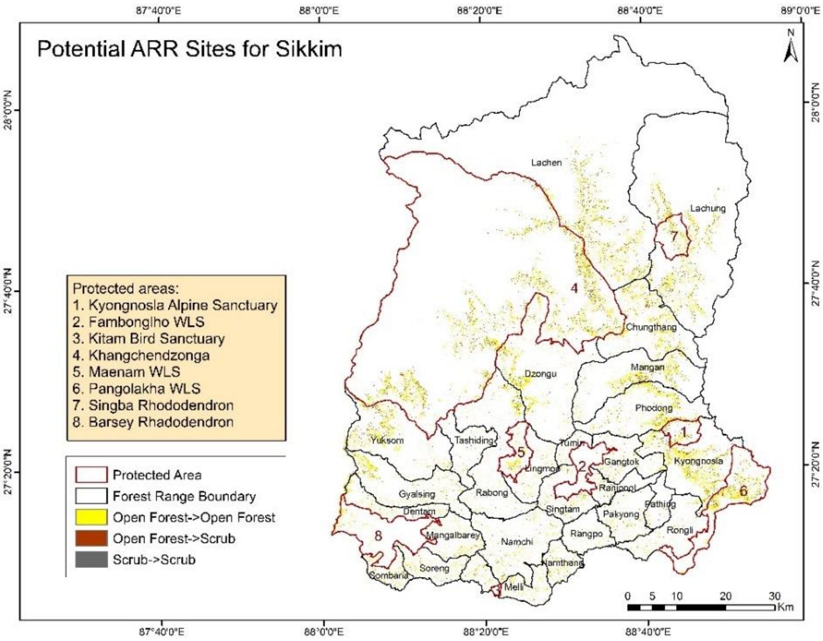


Figure 21 Potential ARR sites for Sikkim; Prepared by TERI

* *Projects within protected areas can only be established for ARR if permitted by the applicable methodology.*

Potential Area based on Land Use Pattern:

An in-depth evaluation of potential sites for Afforestation, Reforestation, and Restoration (ARR) projects has been carried out, considering the forest and non-forest classification within the state. Out of a total assessed area of 492,708.15 hectares, 470.83 hectares (4.70 sq. km.) have been identified as suitable for ARR implementation. Of the 28 forest ranges analyzed, four stand out for their high potential: Chungthang Range, Gangtok Range, Namchi Range, and Namthang Range. Each has more than 40 hectares identified for ARR activities, with 53.86 ha, 45.84 ha, 40.53 ha, and 43.40 ha, respectively. Notably, Chungthang Range exhibits the greatest potential at 53.86 hectares. These four forest ranges (highlighted in Bold), recognized for their significant suitability, are detailed in the table below.

Range-wise Potential Area (Non-Forest Land) 2013 - 2023								
S.no.	**District Name**	**Range name**	**Range Area (in ha)**	**Area Under Agriculture -> Agriculture (in ha)**	**Area Under Agriculture -> Barren (in ha)**	**Area Under Barren -> Agriculture (in ha)**	**Area Under Barren -> Barren (in ha)**	**Total Area under each Range (in ha)**
1	**Mangan District**	**Chungthang Range**	**19347.84**	**0.40**	**3.51**	**3.42**	**46.53**	**53.86**

Range-wise Potential Area (Non-Forest Land) 2013 - 2023								
2	Gyalshing District	Dentam Range	6758.06	0.28	1.08	1.17	7.29	9.82
3	Mangan District	Dzongu Range	30858.15	0.28	0.81	1.44	13.32	15.85
4	**Gangtok District**	**Gangtok Range**	**9070.35**	**0.75**	**2.97**	**5.67**	**36.45**	**45.84**
5	Gyalshing District	Gyalsing Range	16147.09	1.01	2.25	2.70	16.11	22.07
6	Gangtok District	Kyongnosla Range	19330.61	0.17	0.54	1.98	3.42	6.11
7	Mangan District	Lachen Range	121207.88	0.03	0.18	0.09	4.77	5.07
8	Mangan District	Lachung Range	72649.64	0.02	0.09	0.00	2.52	2.63
9	Namchi District	Lingmoo Range	7966.05	1.01	2.43	1.80	7.74	12.98
10	Soreng District	Mangalbarey Range	8300.07	0.67	0.81	0.72	10.08	12.28
11	Mangan District	Mangan Range	20790.46	0.04	0.36	0.18	4.68	5.26
12	Namchi District	Melli Range	8863.14	0.75	1.62	2.16	18.36	22.89
13	**Namchi District**	**Namchi Range**	**18056.10**	**1.20**	**5.31**	**2.52**	**31.50**	**40.53**
14	**Namchi District**	**Namthang Range**	**4813.38**	**0.47**	**4.05**	**1.08**	**37.80**	**43.40**
15	Pakyong District	Pakyong Range	8785.27	0.60	0.45	4.05	22.68	27.78
16	Pakyong District	Pathing Range	4170.62	0.63	1.80	0.72	2.52	5.67
17	Mangan District	Phodong Range	17907.15	0.58	0.36	2.79	5.04	8.77
18	Namchi District	Rabong Range	23526.53	0.53	1.08	0.90	12.78	15.29
19	Pakyong District	Rangpo Range	6454.93	0.32	1.71	0.36	17.28	19.67
20	Gangtok District	Ranipool Range	4913.13	0.34	0.63	1.98	8.91	11.86
21	Pakyong District	Rongli Range	11300.02	0.52	1.17	0.81	5.58	8.08
22	Gangtok District	Singtam Range	7677.97	2.88	2.34	4.86	7.29	17.37
23	Soreng District	Sombaria Range	4319.86	1.56	2.07	6.93	5.22	15.78
24	Soreng District	Soreng Range	6890.63	0.69	1.71	2.43	21.51	26.34
25	Gyalshing District	Tashiding Range	8385.15	0.20	0.63	0.72	7.47	9.02
26	Gangtok District	Tumin Range	2699.97	0.10	0.00	0.18	0.63	0.91

Range-wise Potential Area (Non-Forest Land) 2013 - 2023								
27	Gyalshing District	Yuksom Range	21518.09	0.12	0.63	0.18	4.77	5.70
		Total	492708.15	16.15	40.59	51.84	362.25	470.83

Table 19 Range-wise Potential Area (Non-Forest Land) 2013 - 2023

Potential Area based on Degradation

A detailed assessment of potential ARR (Afforestation, Reforestation, and Restoration) sites based on the degradation within the state has been conducted. From a total assessed area of 492,708.15 hectares, a cumulative area of 5274.09 hectares (52.74 sq. km.) has been identified as suitable for implementing ARR projects. Among the 27 forest ranges evaluated, eight stand out for their high potential (in terms of degraded land): Chungthang Range, Dzongu Range, Kyongnosla Range, Lachen Range, Lachung Range, Mangan Range, Phodong Range, and Yuksom Range. Each has over 300 hectares identified for ARR initiatives. Although Kyongnosla Range, Lachen Range, and Lachung Range exhibit high potential in terms of maximum degraded area, their location in high-altitude zones of the Eastern Himalayas and fragile climatic conditions make them less viable for ARR project development. The extreme environmental factors, including low temperature, limited soil productivity, and harsh weather conditions, pose significant challenges to successful afforestation and long-term carbon sequestration in these regions. After excluding Kyongnosla Range, Lachen Range, and Lachung Range, the remaining five high-potential forest ranges (highlighted in Bold)—Chungthang, Dzongu, Mangan, Phodong, and Yuksom—emerge as the most viable locations for ARR project implementation based on degradation assessment:

Range-wise Potential Area (Degraded Forest Land) 2013 - 2023						
S.no.	**District Name**	**Range name**	**Range Area (in ha)**	**Area Under Scrub -> scrub (in ha)**	**Area Under Open Forest -> Scrub (in ha)**	**Total Area under each Range (in ha)**
1	**Mangan District**	**Chungthang Range**	**19347.84**	**114.84**	**268.83**	**383.67**
2	Gyalshing District	Dentam Range	6758.06	12.33	67.86	80.19
3	**Mangan District**	**Dzongu Range**	**30858.15**	**69.48**	**233.64**	**303.12**
4	Gangtok District	Gangtok Range	9070.35	27.00	82.98	109.98
5	Gyalshing District	Gyalsing Range	16147.09	34.92	139.77	174.69
6	Gangtok District	Kyongnosla Range	19330.61	220.23	339.84	560.07
7	Mangan District	Lachen Range	121207.88	270.81	664.20	935.01
8	Mangan District	Lachung Range	72649.64	257.76	405.90	663.66
9	Namchi District	Lingmoo Range	7966.05	5.04	37.62	42.66
10	Soreng District	Mangalbarey Range	8300.07	6.39	55.62	62.01

Range-wise Potential Area (Degraded Forest Land) 2013 - 2023						
11	**Mangan District**	**Mangan Range**	**20790.46**	**171.18**	**224.73**	**395.91**
12	Namchi District	Melli Range	8863.14	24.12	54.00	78.12
13	Namchi District	Namchi Range	18056.10	16.92	98.37	115.29
14	Namchi District	Namthang Range	4813.38	12.51	37.98	50.49
15	Pakyong District	Pakyong Range	8785.27	8.01	47.97	55.98
16	Pakyong District	Pathing Range	4170.62	3.33	17.73	21.06
17	**Mangan District**	**Phodong Range**	**17907.15**	**133.38**	**212.58**	**345.96**
18	Namchi District	Rabong Range	23526.53	21.78	136.53	158.31
19	Pakyong District	Rangpo Range	6454.93	5.22	26.19	31.41
20	Gangtok District	Ranipool Range	4913.13	7.20	34.38	41.58
21	Pakyong District	Rongli Range	11300.02	8.64	40.23	48.87
22	Gangtok District	Singtam Range	7677.97	15.39	49.23	64.62
23	Soreng District	Sombaria Range	4319.86	10.44	51.84	62.28
24	Soreng District	Soreng Range	6890.63	7.29	46.35	53.64
25	Gyalshing District	Tashiding Range	8385.15	4.23	33.93	38.16
26	Gangtok District	Tumin Range	2699.97	2.07	11.79	13.86
27	**Gyalshing District**	**Yuksom Range**	**21518.09**	**122.49**	**261.00**	**383.49**
	Total		492708.15	1593.00	3681.09	5274.09

Table 20 Range-wise Potential Area (Degraded Forest Land) 2013 - 2023

Eligibility Assessment of Existing Plantation under Government Schemes:

Several government initiatives in Sikkim support plantation activities, including the MRMS, CAMPA, and other conservation schemes. The locations of the plantation sites were provided by The Forest and Environment Department of Sikkim. These sites were then compared with the Land Use/Land Cover (LULC) data and analysed using Google Earth Pro to assess their suitability for ARR projects. CAMPA sites were excluded from consideration, as they are designated for compensatory plantation activities and cannot be utilized for ARR.

A total of 1,152 locations for the MRMS and 20 plantation sites for other schemes and conservation initiatives have been evaluated using Google Earth based on ARR eligibility criteria. The 20 plantation sites, which are part of other schemes and conservation efforts, were deemed ineligible for the following reasons:

- The locations are situated within areas with dense tree cover.
- The dense tree cover has been persistent since 2013.

- Several sites did not display any plantation activity throughout the ARR analysis period, falling under barren or grassland categories, with some areas showing sparse vegetation (canopy cover less than 15%).

Based on the preliminary assessment of the MRMS locations, the following observations were made:

- A total of 33 plantation sites in the Excel sheet have 0 as both latitude and longitude.
- A total of 48 plantation sites are located outside the state boundary.

After excluding these 81 locations, the assessment was conducted on a total of 1,071 points. The distribution of these points by district is as follows:

Number of MRMS points in each division:

Name	District	Count
East district	Gangtok district	327
North district	Mangan district	139
South district	Namchi district	300
West district	Gyalshing district	18
West district	Soreng district	93
East district	Pakyong district	194

Table 21 Number of MRMS Points in each Division

The sites were subsequently extracted for analysis within protected areas to determine how many fell within these regions. Plantation sites located within protected areas cannot be considered due to restricted human intervention. A total of 22 plantation sites were identified within the protected areas.

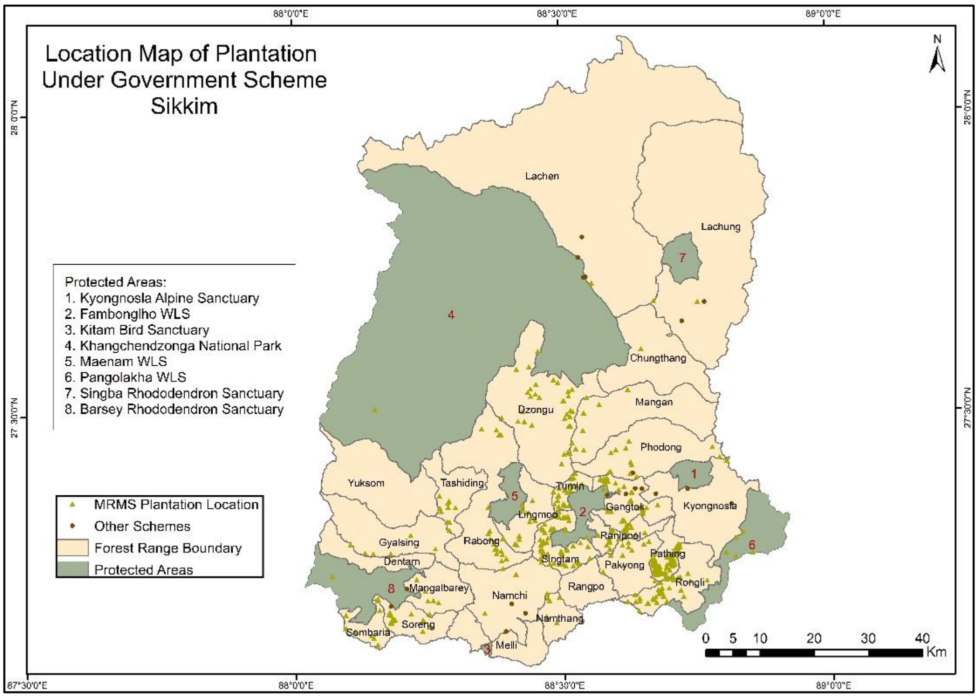


Figure 22 Location Map of Plantation Under Government Scheme, Sikkim; Prepared by TERI

A total of 1,049 plantation sites were analysed by overlaying them onto the Land Use and Land Cover (LULC) data for the years 2013 and 2023 (Fig 23). It was observed that only 59 sites were classified as non-forest in 2013. Of these, 21 sites partially met the criteria, as they exhibited a canopy cover of more than 15% in 2023. Further analysis by overlaying the LULC data for 2017 and 2021, revealed that only 6 sites were consistently classified as non-forest in 2013, 2017, and 2021, and had a canopy cover of over 15% in 2023.

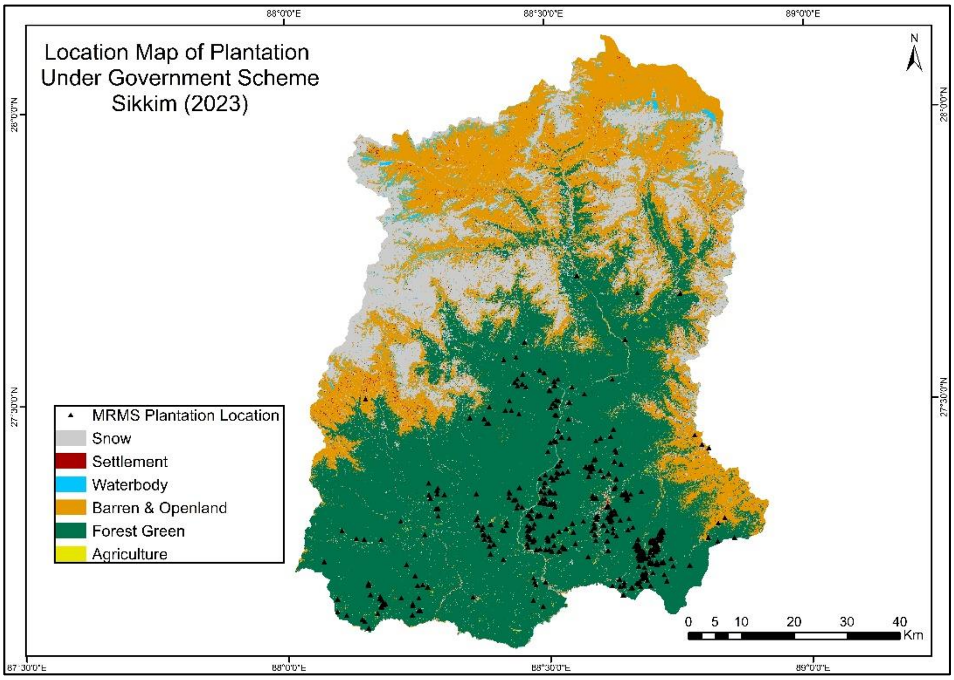


Figure 23 Location Map of Plantation under Government Scheme, Sikkim; Prepared by TERI

2. Assessment of Potential Sites for REDD/REDD+

Permanent Degradation Patch Assessment

An analysis of degradation patches was conducted for the initial year (2009) and the final year (2023) to assess the persistence of these areas. The results of this degradation analysis were compared with both long-term and successive degradation patterns. Degradation patches from seven distinct time periods (long-term and successive) were overlaid with those from 2009-2023 to identify consistent patterns. Areas of degradation that remained consistent throughout the analysis were identified as potential sites for carbon finance project development (Fig 24).

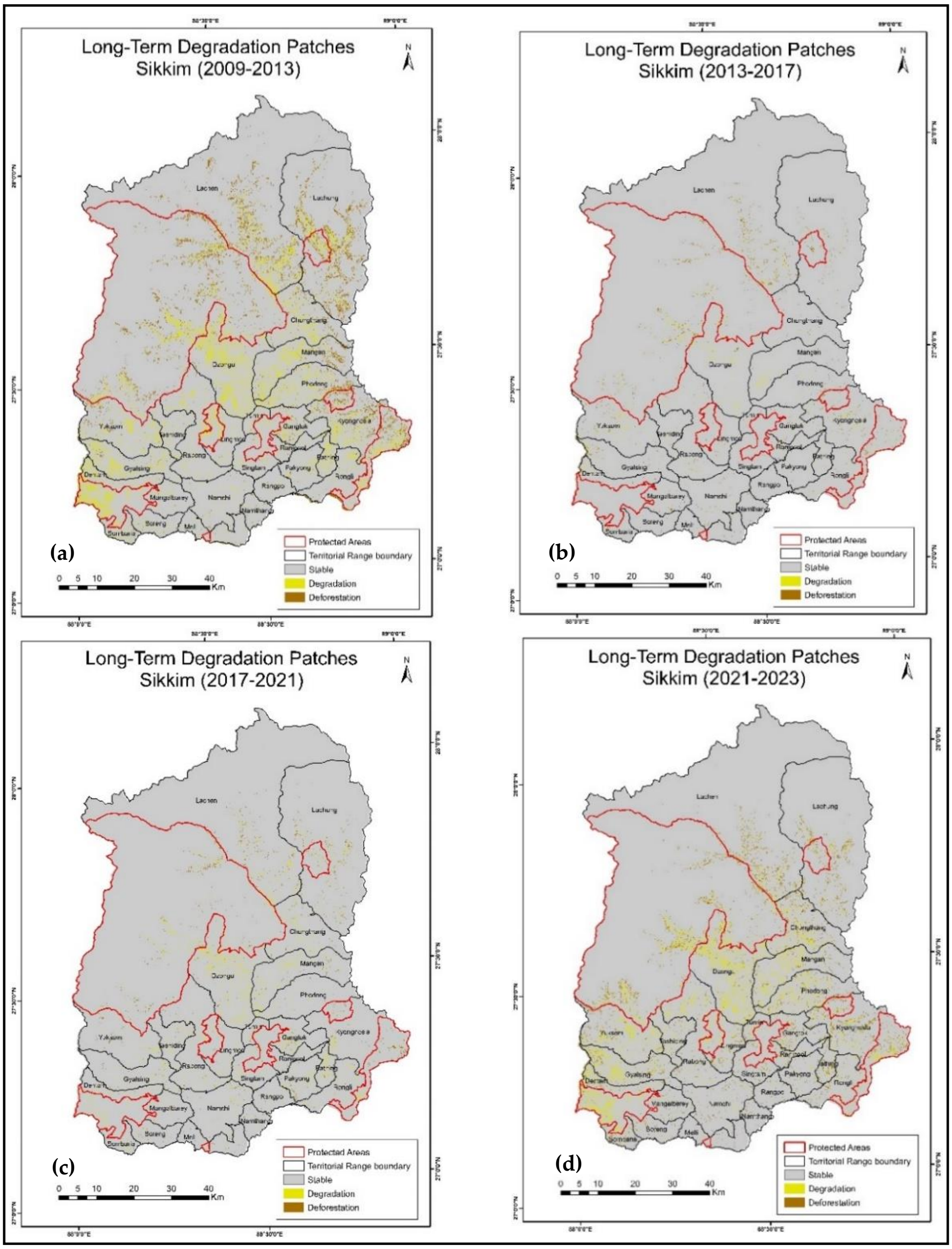


Figure 24 Long-term Degradation Patches (a) 2009-13, (b) 2013-17, (c) 2017-2021, (d) 2021-23; Prepared by TERI

The maps above provide information on long-term continuous degradation patches across four time points.

According to the observations, degradation patches decreased between 2009 and 2013. However, from 2013 onward, a gradual increase in degradation patches has been recorded in Dzongu, Mangan, Gyaising, and Yuksom. Statistical analysis indicates that both degradation and deforestation patch areas gradually decreased by approximately 200 square kilometers during this period. However, a significant increase in both categories was observed thereafter, with a sharp rise of approximately 100 square kilometers occurring between 2021 and 2023.

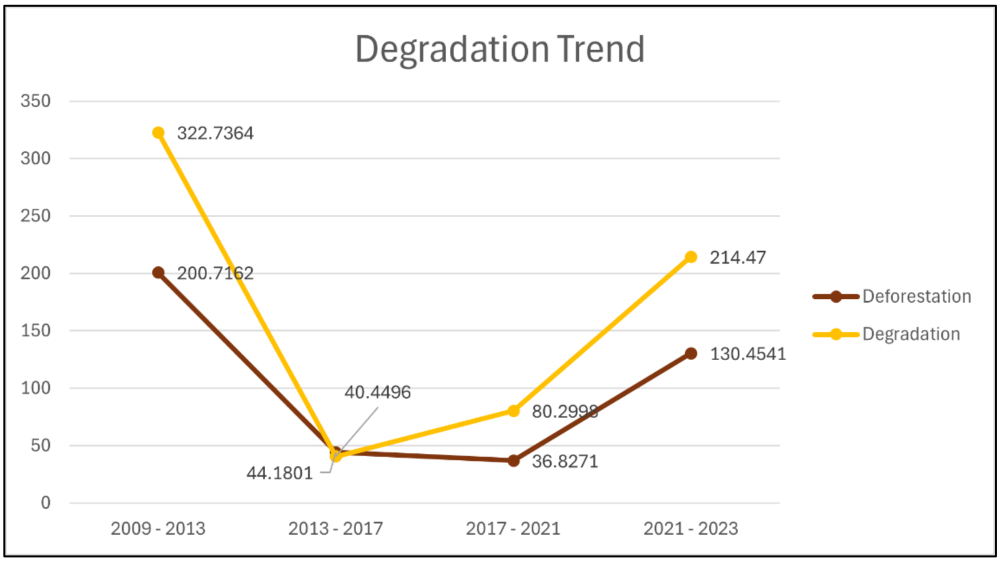


Figure 25 Permanent Degradation Trend

The maps below illustrate short-term continuous degradation patches across three distinct time periods (Fig 26):

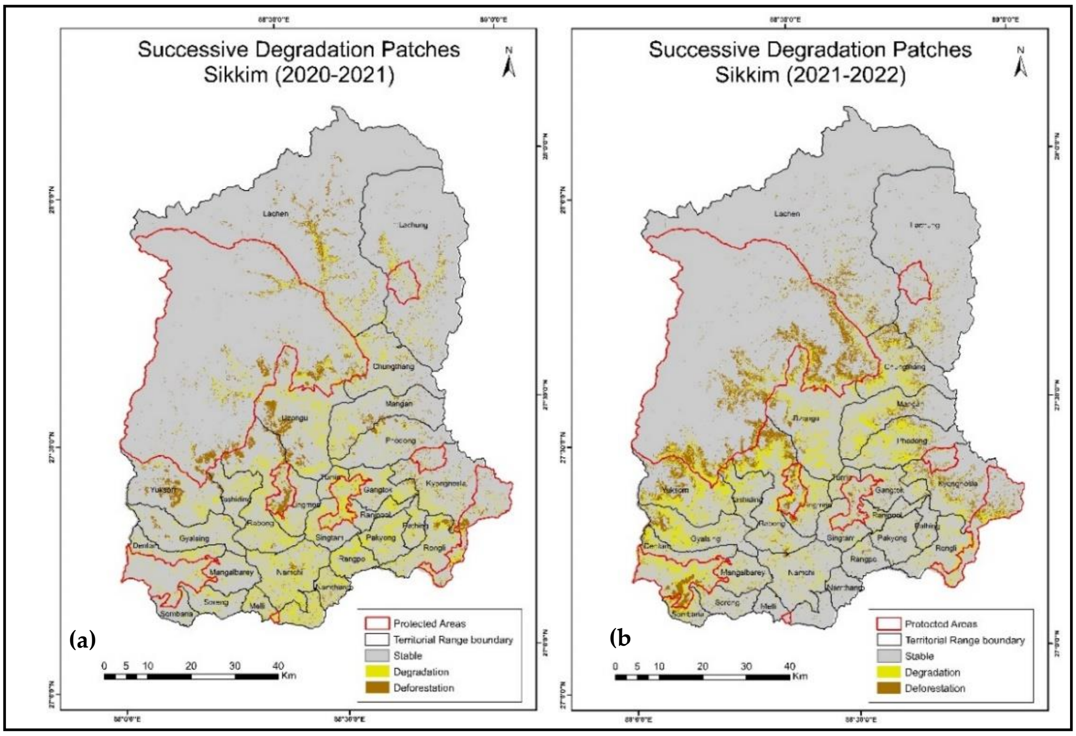
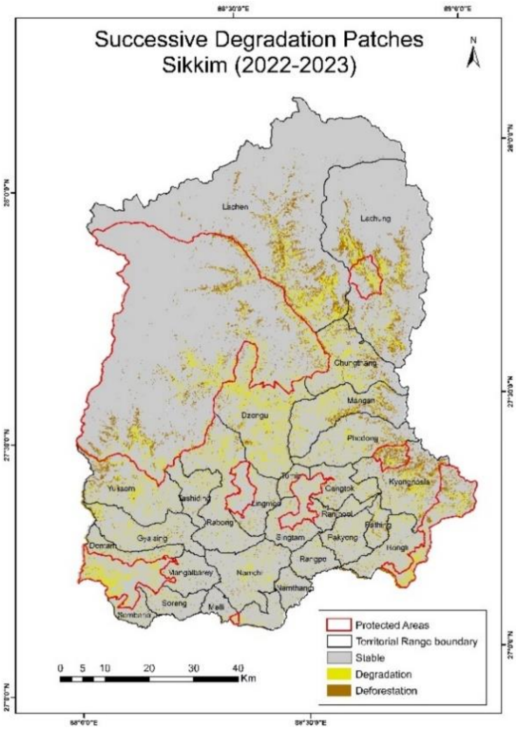


Figure 26 Successive Degradation Patches (a) 2020-21, (b) 2021-22; Prepared by TERI

Observations indicate an increase in continuous degradation patches after 2022, followed by a reduction of 50 square kilometers. Visual analysis shows that degradation patches are predominantly concentrated in the Dzongu, Chungthang, Mangan, Phodong, and Kyongnosla range boundaries



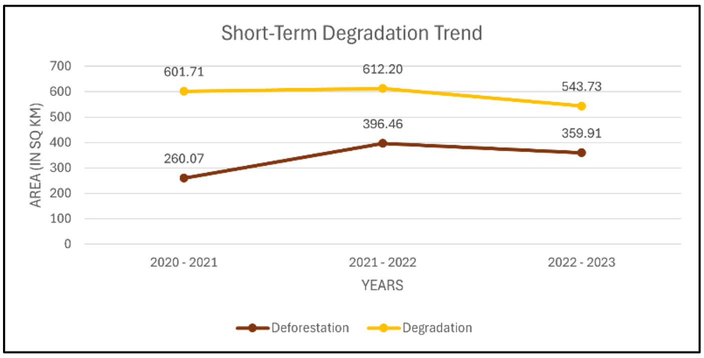


Figure 27 Short Term Degradation Trend

Figure 28 Successive Degradation Patches 2022-23; Prepared by TERI

The delineation of the project boundary further depends on the altitude and accessibility of the location. For instance, the location with high altitude cannot be made as project sites as the altitude might affect the survival rate of the species that are to be planted. Areas demarcated as protected areas become inaccessible for carbon finance projects involving plantation unless the methodology supports it.

Range wise Degradation

The forest range in Sikkim covers a total area of 4,927.08 sq. km, accounting for 69.38% of the state's total geographic area. Within this area, 27 individual ranges have been identified, of which seven demonstrate a statistically significant increase in degradation over recent years. Notably, degradation in the Rabong Range has shown an upward trend since 2009, whereas the remaining six ranges began to exhibit similar trends from 2013 onwards. Together, these seven ranges occupy 1,233.75 sq. km, which accounts for 25.04% of the total forest range area in Sikkim. The following table details the percentage change in degradation across these ranges over a 14-year period.

Time Period wise Degradation Trend (in %)				
Range Name	2009-2013	2013-2017	2017-2021	2021-2023
Chungthang Range	13.97	4.44	12.91	21.11
Dzongu Range	23.00	5.90	16.69	25.51
Gyalsing Range	27.85	6.27	12.98	23.58
Mangan Range	16.96	4.84	12.59	17.63
Rabong Range	7.68	16.61	18.79	23.70
Sombaria Range	24.47	5.62	14.25	19.41
Tashiding Range	10.79	9.58	20.16	20.52

Table 22 Time Period-wise Degradation Trend for RFA (in %)

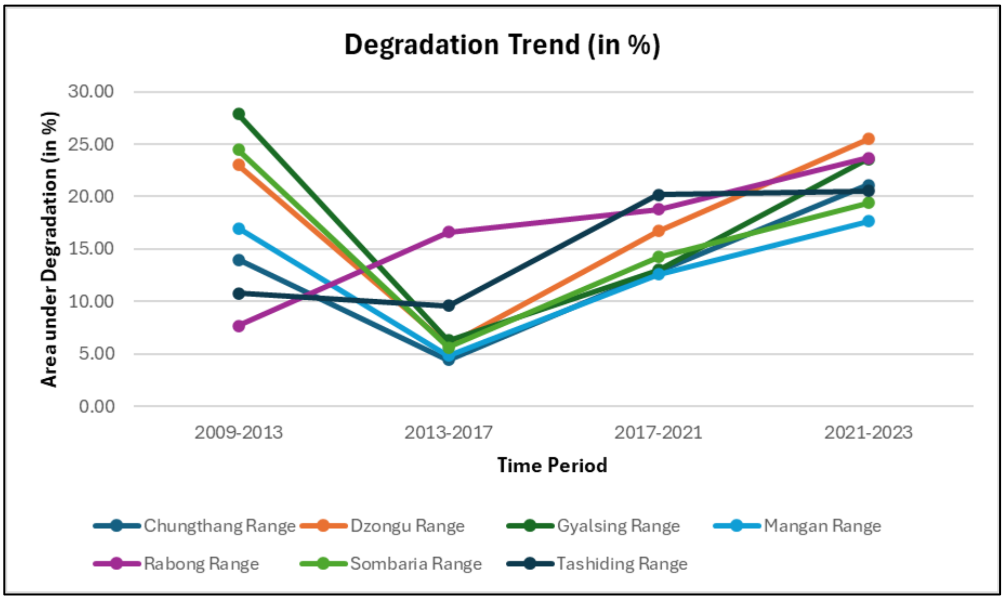


Figure 29 RFA Level Degradation Trend in Percentage, Sikkim

Protected Area Degradation

Sikkim's protected areas encompass a total of 2,167.17 sq. km, representing 30.51% of the state's geographical area. Among these, eight distinct zones have been designated as protected areas, with three showing notable increases in degradation over recent years. Together, these three zones cover 1,892.67 sq. km, which makes up 87.33% of Sikkim's protected land. The following table details the percentage change in degradation across these ranges over a 14-year period.

Time Period wise Degradation Trend (in %)				
Protected Area	2009-2013	2013-2017	2017-2021	2021-2023
Barsey Rhododendron Sanctuary	30.81	2.71	8.99	38.82
Khangchendzonga National Park	3.08	2.54	1.96	6.05
Kyongnosla Alpine Sanctuary	6.06	2.02	2.17	6.45

Table 23 Time Period wise Degradation Trend for Protected Area (in %)

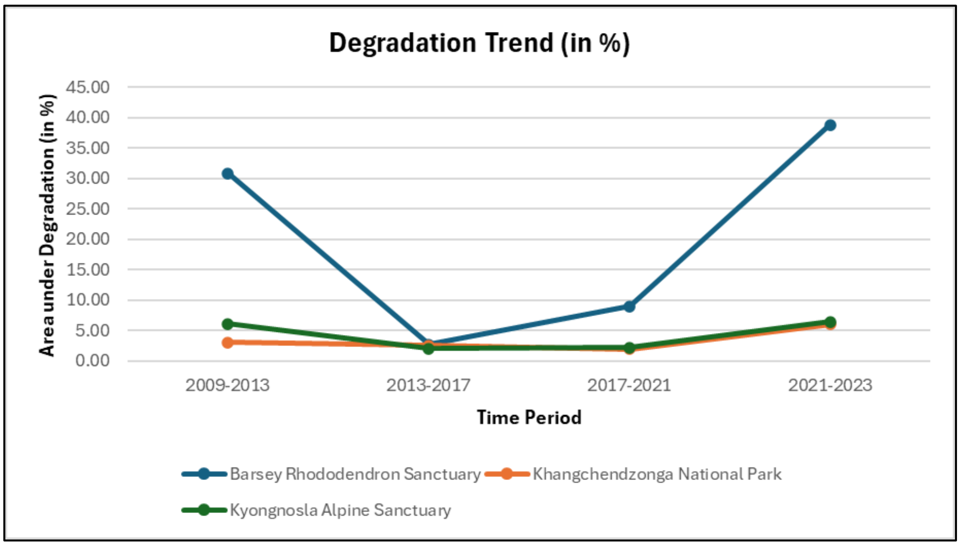


Figure 30 Degradation Trend of Protected Areas in Percentage, Sikkim

Identification of Drivers

Human activities are major contributors to forest degradation, as they directly or indirectly affect the quality of Forests. The impact of population growth, fire, and land use patterns further intensify the decline of forest cover. The primary anthropogenic drivers of forest degradation in the study area are included below:

Resource Extraction and Illegal Activities

Forest is an essential component of various ecosystem services. Local people depend on forest resources for various products such as fuelwood, construction materials, medicine, and food [10] These resources are particularly crucial in regions like the Barsey-Singalila transboundary area within the Khangchendzonga landscape (KL), where diverse ethnic and social groups possess rich traditional knowledge on bioresource utilization. This deep connection to the forest has supported the livelihood of the local communities for generations [45] . Agriculture, livestock, and tourism are the primary sources of livelihood for the community. Common crops grown in the area include potato, maize, oat (barley), bean, yacon (Smallanthus sonchifolius), rayosaag (type of green leafy vegetable), pea, cabbage, radish, and squash.

Households with low incomes and small landholdings often depend heavily on forest resources [1] , particularly in forested regions where about 10% have little to no land, and 50% rely on forests for daily needs and purposes like medicine [35] . These communities, combining farming, livestock, and forest use for income, face growing pressure due to population increases and rising demand for fuelwood, fodder, timber, and non-timber forest products, threatening the balance between resource use and ecosystem preservation [7] .

Due to this, there is a significant disparity between the demand for timber, particularly for constructing houses and cowsheds, and the actual production rate. This gap is evident in the timber requirements of Ribdi - Bhareng compared to the available wood production, resulting in a substantial shortfall. Since only a small portion of firewood is sourced from agricultural fields, the resource demands and production in the villages are largely influenced by their production and utilization patterns.

Communities in villages of the state also rely on local medicinal plants to treat health issues such as indigestion, spasms, chronic fever, dysentery, and influenza, utilizing various plant parts like roots, fruits, leaves, or the entire plant. These medicinal plants are primarily found at elevations ranging from 800 to 3600 meters above sea level in the Himalayas [36]. However, preferred species are harvested extensively for multiple purposes, including fuelwood, leading to significant pressure on a limited group of plants. The trade in medicinal herbs remains disorganized and secretive, resulting in an unstable and unsustainable supply chain. This situation not only depletes the resource base but also exploits rural communities, who act as the primary stewards of these resources. Furthermore, it leads to adulteration and limits the availability of quality herbal drugs for both domestic use and export [11], [52] The lack of effective resource management policies exacerbates these challenges, and delays in implementing such policies risk further biodiversity loss and ecosystem degradation.

Biomass consumption in Sikkim increases with altitude due to various socio-economic and environmental factors. Studies have shown that households at higher elevations rely more on biomass because of limited access to modern fuels and energy infrastructure [50] . This is compounded by the colder climate at higher altitudes, which increases the need for heating homes and water, with firewood being the primary energy source [54].

Agricultural productivity in these regions is constrained by rugged terrain and shorter growing seasons, further intensifying dependence on forest resources, including biomass [55]. Traditional practices and cultural norms also play a role, as many high-altitude communities continue to use biomass for cooking and heating due to familiarity and availability [8] .

The proximity of higher-altitude areas to forested regions provides easy access to biomass, reducing reliance on costlier alternatives such as LPG, which are difficult to transport to remote areas [40] . Despite lower population densities, the per-household biomass demand in these regions is higher due to climatic and practical necessities [48].

However, the increasing consumption of biomass has significant environmental implications, including degradation, habitat loss, and soil erosion, threatening the region's ecological balance.

Shifting Cultivation

Shifting cultivation, also known as Jhum Cultivation or *Sudyom Prek Shyon/Sudyom Hong Shyong* in Sikkim, is a traditional agricultural practice historically prevalent among the local communities of the region. It has been a key subsistence strategy, particularly in the hilly and forested terrains, due to its adaptability to the natural conditions of the area. Although shifting cultivation has been widely replaced by sedentary agricultural practices in Southeast Asia [51], it persists in some parts of Sikkim, where indigenous groups like the Lepcha tribe continue practicing it on a limited scale to preserve their cultural heritage.

The Wildlife (Protection) Act of 1972, which governs the establishment of protected areas for wildlife conservation, prohibited shifting cultivation in Sikkim due to its perceived risks of forest fires, deforestation, and land degradation, especially in the protected and reserved forest areas that adjoin the community's land [23]. Gradually, shifting cultivation began transitioning into terrace farming and cardamom plantations with the arrival of migrant laborers [5]. In later years, the legal restrictions and associated penalties further accelerated the shift to settled agriculture, resulting in the disappearance of shifting cultivation in most parts of the state.

Despite the widespread decline of shifting cultivation, remnants of this practice persist in certain regions of Sikkim, particularly in the Dzongu Valley. Reports indicate that as recently as 2020-2021, this practice was observed in villages such as Kusong, Mangzing, Sakyong, Leek, and Pentong [33] .

While the practice of shifting cultivation remains culturally significant for tribal communities, it is associated with ecological concerns such as soil fertility depletion and erosion in higher catchments [2].

With the shift from shifting cultivation to sedentary agricultural practices, the demand for arable land has significantly increased. The development of roads and infrastructure to support local communities has played a crucial role in this transition, linking farming communities to local and distant markets. While these advancements have supported agricultural growth and connectivity to markets, they have also intensified the conversion of forest land to support sedentary and settled farming, contributing to forest degradation and encroachment.

Development Pressure and Tourism

Tourism serves as a vital source of income and employment for the people of Sikkim while contributing to the state's revenue. The unique geographical and economic features of the region, along with its rich cultural heritage, make Sikkim a naturally appealing tourist destination in Northeast India [12]. Recognizing the significant growth potential of the tourism industry in Sikkim and its role in generating employment and income in peripheral regions, the Government of Sikkim has prioritized tourism promotion and development. However, this emphasis, along with various other factors, has led to a rapid proliferation of tourism enterprises in specific pockets. While this has contributed to increased tourism revenues, it has often been at the expense of the state's ecological stability. Many tourism sites have surpassed their capacity limits due to the surge in tourist numbers, posing a serious threat to the sustainability of this eastern Himalayan region.

The East district, home to the state capital Gangtok and surrounding areas, remains the most frequented destination, followed by the South, West, and North districts. Except for the North district, all other regions are experiencing excessive strain due to the combined pressures of local and transient populations, further aggravated by the influx of vehicles brought in from neighbouring West Bengal to meet tourist demands. These factors have significantly increased pressure on the state's land and resources, thereby undermining its sustainability [12]. This rapid expansion of the city is leading to a range of potential challenges. With the growing population, degradation and land encroachment are becoming increasingly prevalent [44].

At the local level, the construction of large-scale structures such as monumental statues, tourist hotels, hydropower dams, and high-rise residential buildings reflects Sikkim's pursuit of development and progress [39]. These rapid changes are intertwined with efforts to enhance the state's appeal as a tourist destination and address the pressures of modernization.

These areas contribute significantly to environmental degradation by depleting vital resources such as air, water, and soil. The extensive use of motor vehicles and reliance on private transport over long distances emit substantial levels of pollutants into the atmosphere [44]. Additionally, degradation and the conversion of agricultural lands pose serious threats to water availability and quality. These activities adversely affect vegetation and habitats, leading to the extinction of various animal and plant species, and ultimately depleting critical environmental resources.

Quantification of Major Drivers of Degradation

Fire Incidents

Forest fires can be influenced by human activities such as the collection of fuelwoods, shifting agriculture, and resin tapping, as well as natural factors like dry weather, high temperature, wind speed, vegetation moisture content, etc. Uncontrolled wildfires pose a threat to the degradation of forests.

The spatial distribution of fire incidents was overlaid on the FVC change layout from 2009 to 2023 (Fig 31). A Total of 200 fire incidents were reported in the past 14 years.

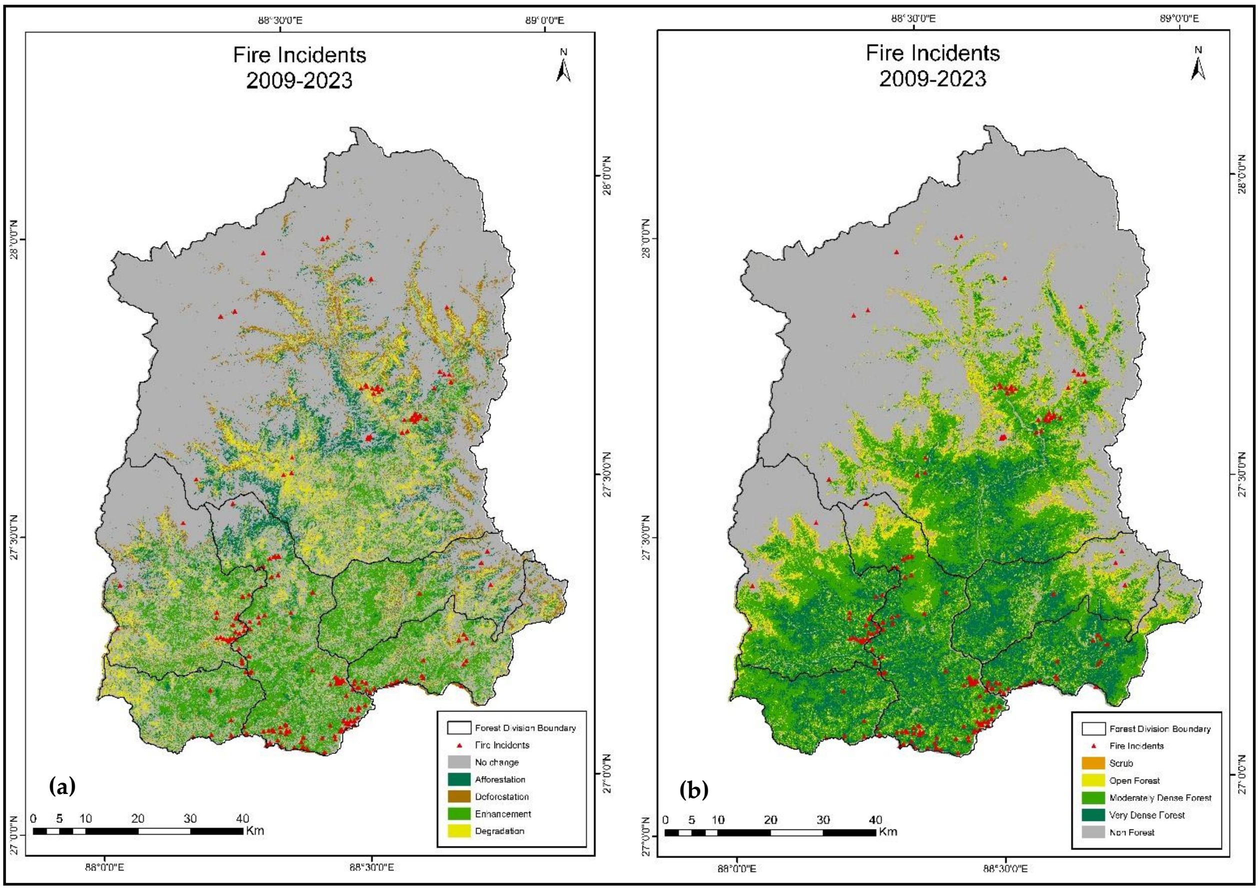


Figure 31 Fire Incidents for 2009-2023 (a) on forest density, (b) on FVC; Prepared by TERI

Spatial overlay analysis of fire incidents with Fractional Vegetation Cover (FVC) changes from 2009 to 2023 shows that 14 incidents led to deforestation, and 12 resulted in forest degradation. Notably, 94 incidents fell under the "no change" category, indicating no significant change in forest quality during this period. Further analysis of the "no change" category, when overlaid onto the FVC 2023, showed that 46 points occurred within moderately dense forests, while 7 points were in very dense forests. This suggests that although these areas have not experienced significant change due to fire activity, they remain vulnerable to future disturbances from fire incidents.

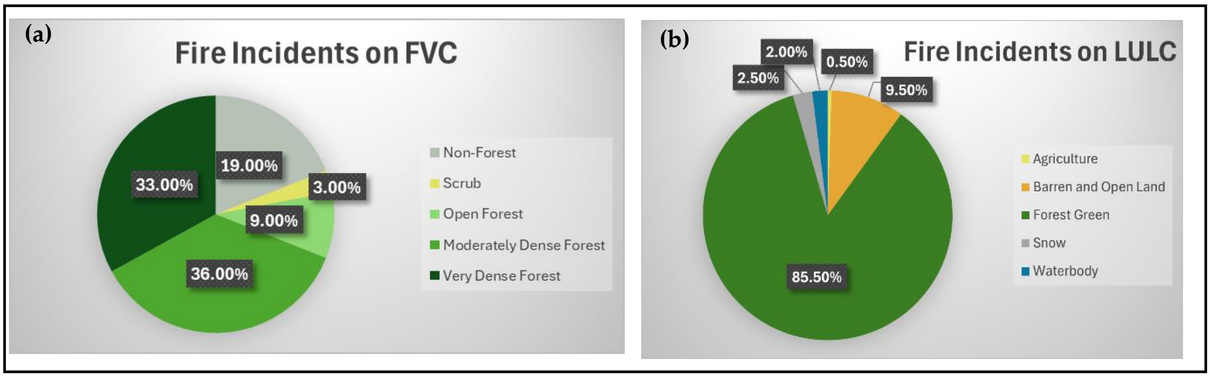


Figure 32 Pie chart for Fire Incidents 2009-23 (a) on FVC, (b) on LULC

As per FVC 2023, out of 200 fire incidents, 66 incidents fell into the VDF region while 72 fire incidents were reported in MDF Region.

Overlaying the fire incidents on the LULC 2023 reveals that 171 of the total fires in the last 12 years have occurred within the forest area region (Fig 32). This indicates that forest areas and managed vegetation areas are particularly vulnerable to fire activity.

Fire Vulnerability Zonation

Active fire products from the Moderate Resolution Imaging Spectroradiometer (MODIS) sensor have been accessed in shapefile format from NASA's Fire Information for Resource Management System (FIRMS) from 2009 to 2023. The MODIS active fire product detects fires in 1 km pixels that are burning at the time of overpass under relatively cloud-free conditions using a contextual algorithm. The spatial data has been processed in the ArcGIS software where hotspot analysis using the Brightness Temperature (T31) is done. According to Mupfiga et al. (2022) [42] hotspot analysis is a tool used to identify high- or low-level clusters within a dataset. T31 represents the brightness temperature in the infrared spectrum, helping to estimate the background temperature associated with fire events. Getis-Ord GI* is applied to detect spatial clustering, assisting in identifying hotspots or cold spots related to fire-prone areas. The resulting GIZ scores obtained from the hotspot analysis are used for Inverse Distance Weighting (IDW) interpolation. The IDW layer has been then categorized into 5 classes based on vulnerability to fire, assigning a value of 5 to regions with a very high risk of fire and a value of 1 to areas very less prone to fires (Fig 33).

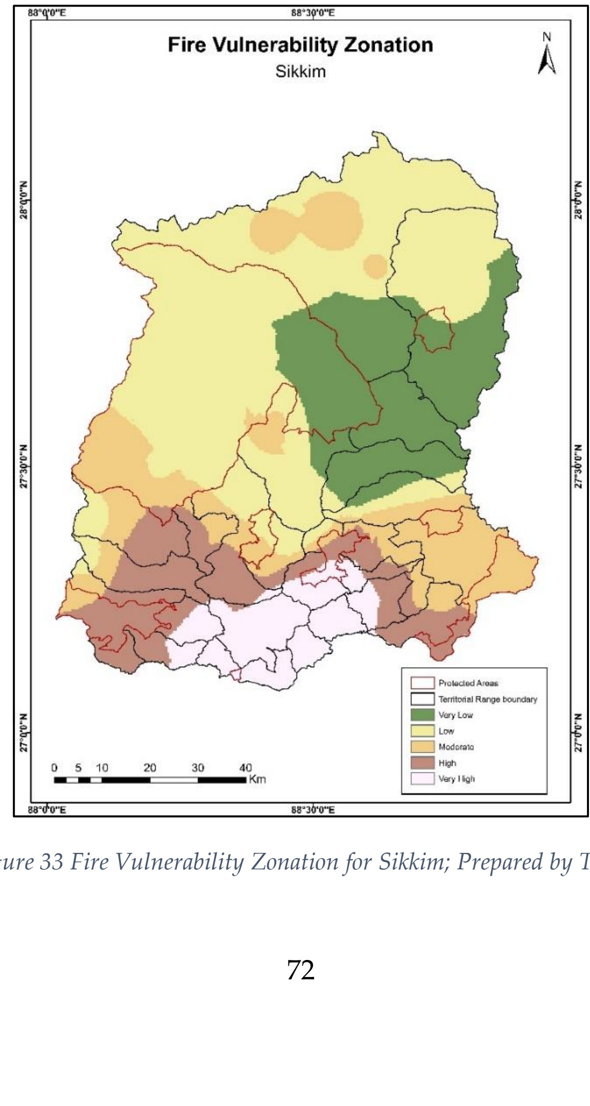


Figure 33 Fire Vulnerability Zonation for Sikkim; Prepared by TERI

Using Zonal Statistics, the vulnerability has been assessed for all 35 forest ranges and protected areas, identifying regions with the highest vulnerability. Out of these, 19 have been classified as having high or very high vulnerability to the effects of fire (Table 24). This indicates that over half of the forest ranges are at significant risk of intense fire.

Name	Vulnerability
Barsey Rhododendron Sanctuary	High
Dentam Range	High
Fambonglho WLS	High
Gyalsing Range	High
Kitam Bird Sanctuary	Very High
Mangalbarey Range	Very High
Melli Range	Very High
Namchi Range	Very High
Namthang Range	Very High
Pakyong Range	High
Rabong Range	High
Rangpo Range	Very High
Ranipool Range	Very High
Rongli Range	High
Singtam Range	Very High
Sombaria Range	High
Soreng Range	High
Tashiding Range	High
Yuksom Range	High

Table 24 Ranges and Protected Areas along with Vulnerability to fire

High fire vulnerability in these forest ranges and protected areas increases the risk of degradation. Intense fires damage forest cover and reduce vegetation. In a later section, an analysis shall identify the regions where forest fires are a key driver of degradation.

Population Growth

The spatial distribution of the population has been analyzed using data from the Global Human Settlement Layer (GHSL) for 2000, 2010, and 2020, and projections for 2030 across forest ranges and protected areas. This analysis highlights the increasing risk of encroachment into forest regions, contributing to degradation. By 2030, the population in Sikkim is projected to reach over 6.8 lakh, reflecting a 22.9% increase since 2000. Further analysis has shown that the population number in the RFA would reach over 43 thousand (Analysis demonstrated in the population distribution in forest area Fig 34).

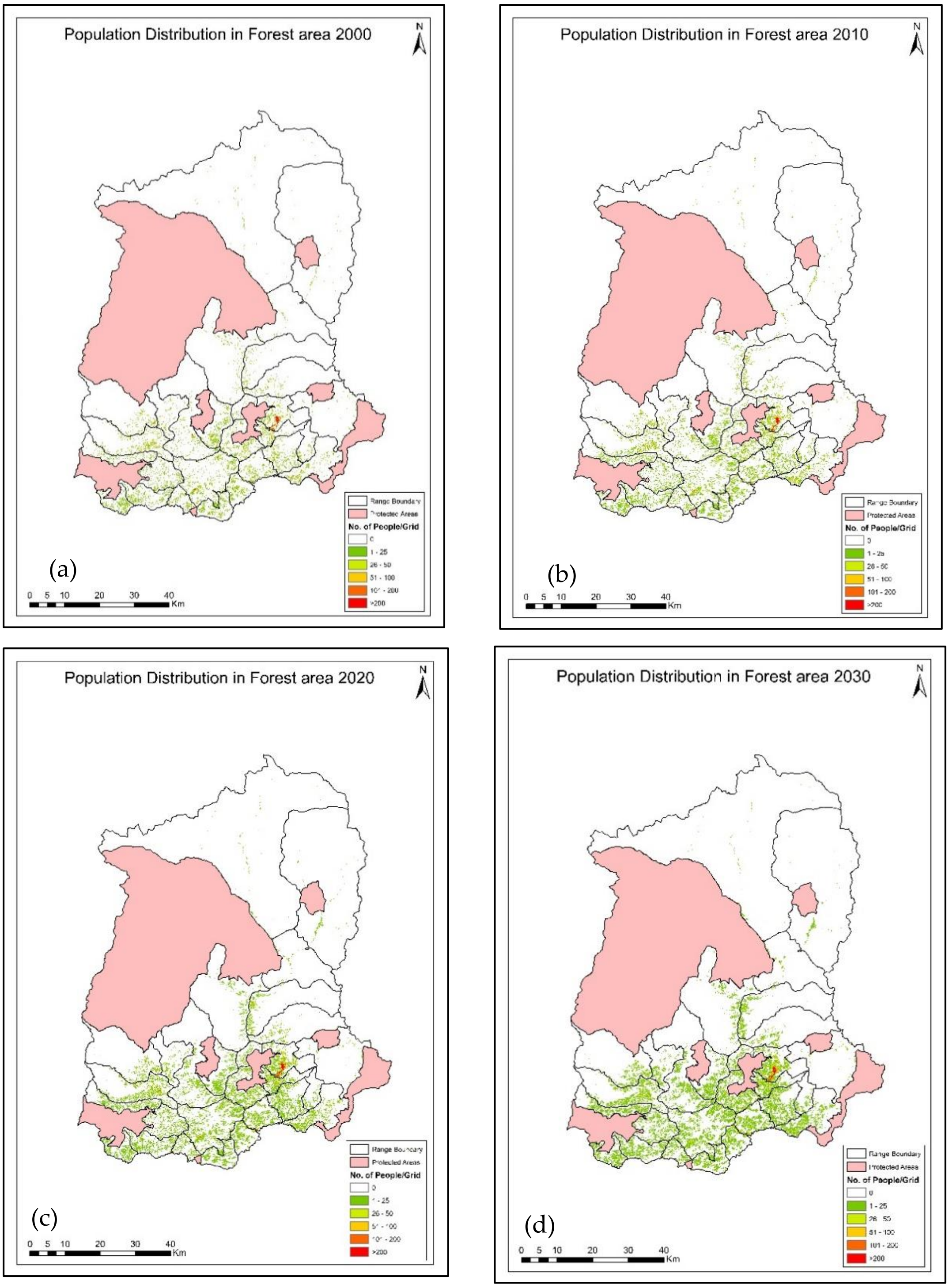


Figure 34 Population Distribution in Forest Area for (a) 2000, (b) 2010, (c) 2020, (d)2030; Prepared by TERI

The population in the Recorded Forest Area (RFA) in Assam and its decadal growth rate is shown in the table below:

Year	Population in Recorded Forest Area	Decadal Growth %
2000	30,757	-
2010	35,557	16
2020	40,684	14
2030	43,818	8

Table 25 Population Growth

The decadal variation in population pressure in the recorded forested area of Sikkim state has been presented in the figure below since the year 2000 for each corresponding epoch:

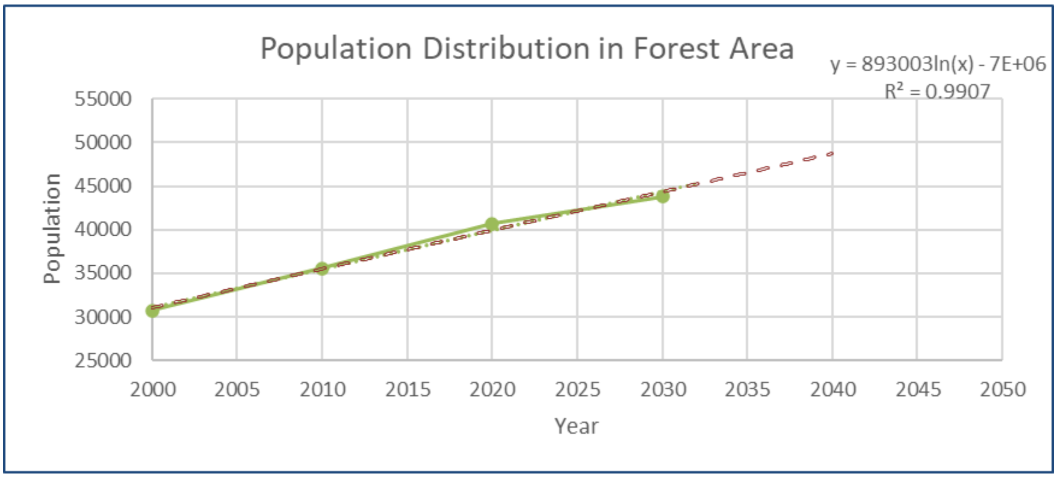


Figure 35 Population Distribution in Forest Area, Sikkim

Population is a significant driver of forest degradation in Sikkim. Of the 35 forest ranges and protected areas, 21 have experienced consistent population growth over 30 years. The continued population growth in these areas adds more pressure on forest resources, increasing the risk of encroachment and contributing to forest degradation.

This consistent population growth within forest areas indicates increased human pressure, contributing to forest degradation. In a later section, an analysis is provided to determine whether the forest ranges showing continuous population growth align with those experiencing consistent degradation over time. Below is the list of the forest ranges where population growth has remained consistent over the past three decades.

Range and Protected Area Name	Population			
	2000	2010	2020	2030
Barsey Rhododendron Sanctuary	353	505	666	802
Dentam Range	10800	13262	16862	17872
Dzongu Range	9327	9582	9524	10306
Fambonglho WLS	962	1196	1578	1939
Gyalsing Range	38177	42981	45992	46462
Kyongnosla Alpine Sanctuary	407	417	418	437
Kyongnosla Range	4552	4913	5888	6314
Lachung Range	2505	2878	3084	3170
Mangalbarey Range	13611	15167	16222	17242
Mangan Range	10110	14352	17980	18235
Namchi Range	47015	53785	59087	62088
Pakyong Range	19771	24188	29112	30842
Rabong Range	15069	18060	22277	24252
Rangpo Range	19605	25108	30145	32548
Ranipool Range	18357	22351	28824	30544
Rongli Range	25702	29171	31205	32294
Singtam Range	25919	31038	37661	42701
Soreng Range	16229	17853	18409	19377
Tashiding Range	8996	9251	9426	10017
Tumin Range	2600	3327	5604	7168
Yuksom Range	15441	16367	16625	17158

Table 26 Division based Population Distribution (2000-2030)

Agriculture Trend Analysis

Agricultural land use in Sikkim exhibited a consistent upward trend until 2021, after which a decline in agricultural area became apparent. A linear projection of this pattern suggests that, if current trends continue, the area under agriculture is anticipated to increase substantially (Figure 36). This observed decline in agricultural land post-2021 was further validated using LULC data from sources such as Bhuvan, ESRI, and other similar organizations, which also reflected a decrease in agricultural land during the same period.

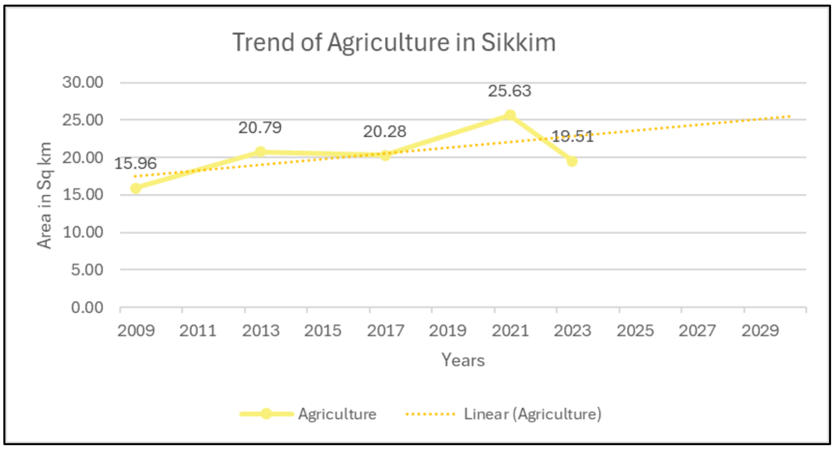


Figure 36 Trend of Agriculture in Sikkim

To assess the potential impacts of this expansion, agricultural land use was further analyzed in relation to forest ranges. This analysis aimed to identify specific ranges where agricultural activities might exert influence, providing insights into potential areas of conflict between agricultural growth and forest conservation.

Four ranges were identified with a consistent increase in agricultural area up to 2021. The details of these ranges, along with the agricultural area recorded for each year of the analysis, are provided below.

Area under Agriculture (2009-2023)								
S.no.	District Name	Range name	Range Area (ha)	Area in ha (2009)	Area in ha (2013)	Area in ha (2017)	Area in ha (2021)	Area in ha (2023)
1	Namchi District	Lingmoo Range	7966	64.53	73.8	104.31	130.59	52.74
2	Namchi District	Melli Range	8863	61.29	87.66	200.34	224.91	83.43
3	Namchi District	Namthang Range	4813	25.74	34.02	161.28	168.12	63.36
4	Soreng District	Soreng Range	6891	83.07	87.12	124.74	173.43	46.08
	Total		28533	234.63	282.6	590.67	697.05	245.61

Table 27 Range wise Area under Agriculture (2009-2023)

Correlation Analysis: Cause and Effect of Forest Degradation

A detailed analysis of population trends and Fire vulnerabilities across various forest regions has identified 7 ranges and 3 protected areas with a persistent rate of degradation. Population data from 2000, 2010, 2020, and projections for 2030 reveal a consistent increase in 18 ranges and 3 protected areas, contributing to mounting pressures on the forest. Furthermore, 16 ranges and 3 protected areas have been categorized as highly or very highly vulnerable to forest fires. Among these, three ranges and one protected area show a critical overlap of consistent population growth and increased vulnerability to forest fires, both major drivers of forest degradation. Increasing populations place greater pressure on forests due to habitat encroachment, resource extraction, and land use changes, as highlighted in the literature review. At the same time, the growing risk of forest fires, intensified by human activities, contributes to further deterioration of forest cover.

Degradation due to increasing population and High Risk of Fire
Barsey Rhododendron Sanctuary
Gyalsing Range
Rabong Range
Tashiding Range

Table 28 Areas with High Fire Risk and Population

Accuracy Assessment

Accuracy Assessment of FVC Map 2023

For the accuracy assessment, the ground truth points (or reference/testing points) were plotted using a stratified random sampling method and overlain on Google Earth images for accuracy assessment. An error matrix (also known as confusion matrix or contingency matrix) was prepared along with a map highlighting the ground truth points

The accuracy assessment and Kappa coefficient values of the Forest Density analysis conducted for the year 2009 and 2023 are presented in the table below:

FVC Accuracy Assessment 2009 and 2023				
	2009		2023	
Class	**User Accuracy**	**Producer Accuracy**	**User Accuracy**	**Producer Accuracy**
Scrub	80.00	80.00	80.00	88.89
Open Forest	86.96	86.96	82.35	77.78
Moderately Dense Forest	89.83	96.36	84.00	91.30
Very Dense Forest	89.29	80.65	93.55	82.86
Non-Forest	96.70	95.65	94.90	94.90

Table 29 FVC Accuracy Assessment 2023

Accuracy Assessment with Error Matrix – 2009 and 2023	2009		2023	
	Kappa Coefficient = 0.88		Kappa Coefficient = 0.86	
	Overall Accuracy = 92.23%		Overall Accuracy = 90.29%	
Class	**Commission (%)**	**Omission (%)**	**Commission (%)**	**Omission (%)**
Scrub	20.00	20.00	20.00	11.11
Open Forest	13.04	13.04	17.65	22.22
Moderately Dense Forest	10.17	3.64	16.00	8.69
Very Dense Forest	10.71	19.35	6.45	17.14

Accuracy Assessment with Error Matrix – 2009 and 2023	2009		2023	
	Kappa Coefficient = 0.88		Kappa Coefficient = 0.86	
	Overall Accuracy = 92.23%		Overall Accuracy = 90.29%	
Non-Forest	3.30	4.35	5.10	5.10

Table 30 Accuracy Assessment Error Matrix

The following map highlights the ground truth points used for the accuracy assessment of Forest Density for the years 2009 and 2023 (Fig 37).

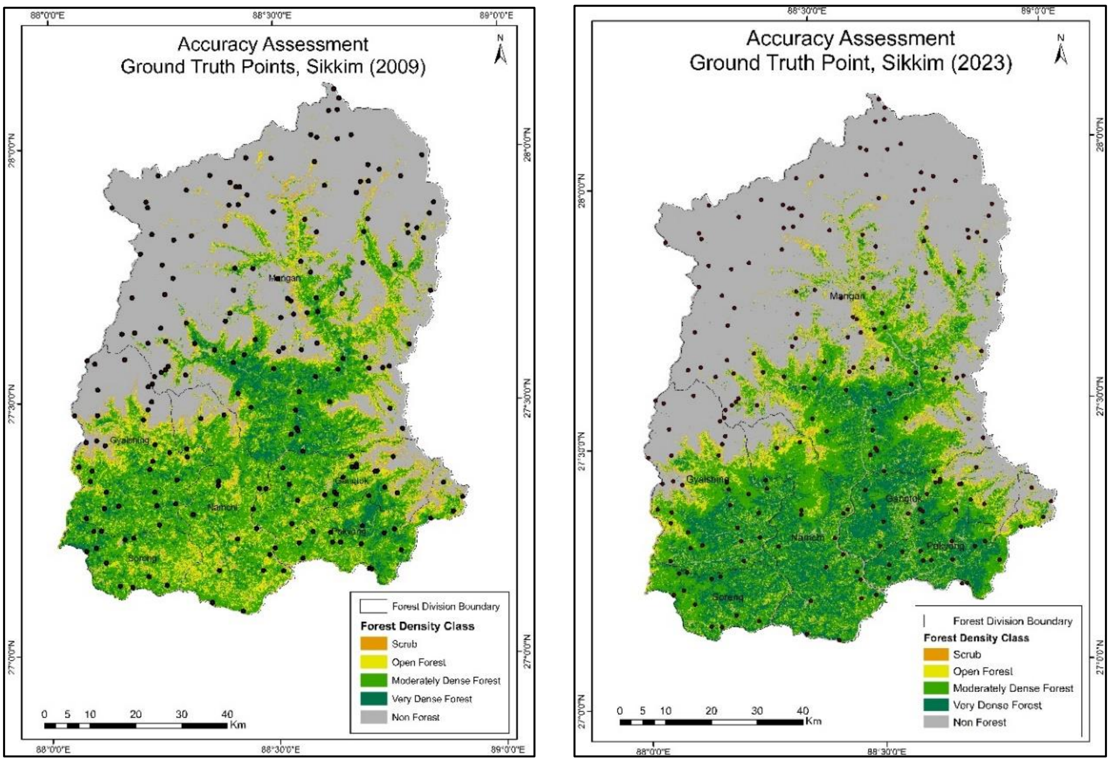


Figure 37 Ground Truth Points for Accuracy Assessment: (a) 2009, (b) 2023. Prepared by TERI

Accuracy Assessment of LULC 2023

For the accuracy assessment, the ground truth points (or reference/testing points) were plotted using stratified random sampling method and overlain on Google Earth images for accuracy assessment. An error matrix (also known as confusion matrix or contingency matrix) was prepared along with a map highlighting the ground truth points

The accuracy assessment and Kappa coefficient values of the Land Use Land Cover analysis conducted for the year 2009 and 2023 are presented in the tables below:

LULC Accuracy Assessment 2009 and 2023				
	2009		2023	
Class	User Accuracy	Producer Accuracy	User Accuracy	Producer Accuracy
Snow	91.18	83.78	91.18	86.11
Settlement	80.00	88.89	80	88.89
Waterbody	80.00	100.00	80	88.89
Barren and Open land	93.62	86.27	92	82.14
Forest Green	92.71	96.74	92.47	98.85
Agriculture	80.00	80.00	80	80

Table 31 LULC Accuracy assessment 2023

Accuracy Assessment with Error Matrix – 2009 and 2023	2009		2023	
	Kappa Coefficient = 0.86		Kappa Coefficient = 0.86	
	Overall Accuracy = 90.82%		Overall Accuracy = 90.33%	
Class	Commission (%)	Omission (%)	Commission (%)	Omission (%)
Snow	8.82	16.22	8.82	13.89
Settlement	20.00	11.11	20.00	11.11
Waterbody	20.00	0.00	20.00	11.11
Barren and Open land	6.38	13.73	8.00	17.86
Forest Green	7.29	3.26	7.53	1.15
Agriculture	20.00	20.00	20.00	20.00

Table 32 Accuracy Assessment Error Matrix 2023

The following map highlights the ground truth points used for the accuracy assessment of Forest Density for the years 2009 and 2023 (Fig 38).

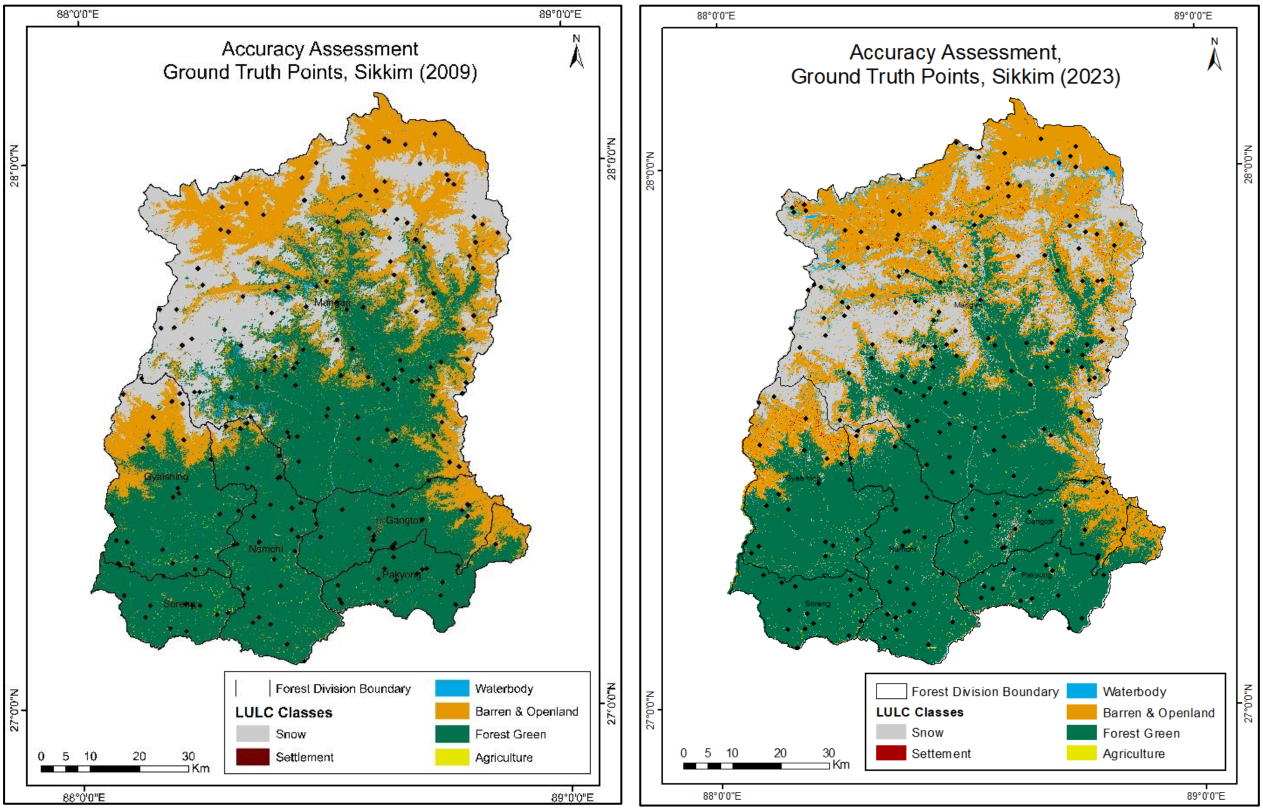


Figure 38 LULC Accuracy Assessment Ground Truth Points; Prepared by TERI

Comparison with High-Resolution Data

In alignment with the existing guidelines as listed in the VERRA methodology, the years chosen for the historical change analysis were 2009, 2013, 2017, 2021, and 2023. However, cloud-free satellite imagery for Sikkim is available from 2017-18. To ensure consistency in the historical analysis of land use patterns and forest cover, all imagery used must have the same spatial resolution and exhibit similar phenological variations. Given these constraints, it was concluded that utilizing Landsat imagery is the most optimal solution for this study.

Additionally, a correlation analysis was conducted between findings from the Landsat series and Sentinel data to evaluate the accuracy of the analysis performed using Landsat imagery. A detailed comparative analysis was performed for the present year, which will allow for validation and cross-referencing of the results, ensuring the reliability of the analysis. The results of this analysis have been added in the annexure.

Feasibility for Plantation in the Potential Sites for ARR

In this section we have tried to identify the number of credits that can be generated by plantation activities in the identified eligible areas. In addition, financial feasibility is also performed (*taking suitable assumptions, wherever necessary*) that will assist Renew in taking informed decision.

The potential sites (non-forest) identified for plantation activity are as follows:

District Name	Range name	Range Area (in ha)	Eligible Plantation Area under each Range (in ha)
Mangan District	Chungthang Range	19347.84	53.86
Gangtok District	Gangtok Range	9070.35	45.84
Namchi District	Namchi Range	18056.1	40.53
Namchi District	Namthang Range	4813.38	43.4
Total			**183.63**

The potential sites in the degraded forests identified for plantation activity are as follows:

District Name	Range name	Range Area (in ha)	Eligible Plantation Area (in ha)
Mangan	Chungthang	19347.84	383.67
Mangan	Dzongu	30858.15	303.12
Mangan	Mangan	20790.46	395.91
Mangan	Phodong	17907.15	345.96
Gyalshing	Yuksom	21518.09	383.49
Total			**1812.15**

Therefore, the total potential area available for plantation activities is around 1995 ha. These have been checked for the eligibility criteria as per the VCM standards and methodologies.

The following points have been considered for calculating the estimated ER and financial viability:

1. The density of the plantation is taken as 919 trees per ha. (Source: Pradhan, Bharat & Lamsal, Dharmendra & Sharma, Durga. (2023). Assessment of Degraded Forests in Sikkim.)

2. The annual biomass increment in (t/ha) for Sub-tropical forest of Sikkim has been taken as 2.19 (Source: Devi, N. & Lepcha, Nima & Mahalik, Siddarth & Dutta, Denish & Tsanglao, Benrithung. (2021). Urban sacred grove forests are potential carbon stores: A case study from Sikkim Himalaya. Environmental Challenges. 4. 100072. 10.1016/j.envc.2021.100072.)
3. Cost of plantation of each tree is INR 70 (Based on the discussion with experts)
4. Carbon Credit from the project is sold at USD 15 (Based on the discussion with experts); (1 USD = 85 INR)

Based on the density, total number of trees that will be planted. The species that are suitable for plantation in the state are listed in Annexure V.

Type of degraded land	Eligible Area (ha)	Density	Total trees to be planted
Agriculture	183.63		
Forest Land	1812.15		
Total	**1995.78**	919	**18,34,122**

For plantation activity, 2 scenarios have been considered. The financial feasibility is identified by calculating the NPV in the both the scenarios.

Scenario 1: All the trees are planted in the same year in 2026. The ERs are as follows:

Year	Period	Total Biomass (tonnes)	Total carbon (tC)	VCUs' (tCO2e)
0	Baseline year	0	0	0
1	1st January 2026 - 31st December 2026	4371	2054	7539
2	1st January 2027 - 31st December 2027	4371	2054	7539
3	1st January 2028 - 31st December 2028	4371	2054	7539
4	1st January 2029 - 31st December 2029	4371	2054	7539
5	1st January 2030 - 31st December 2030	4371	2054	7539
6	1st January 2031 - 31st December 2031	4371	2054	7539
7	1st January 2032 - 31st December 2032	4371	2054	7539
8	1st January 2033 - 31st December 2033	4371	2054	7539
9	1st January 2034 - 31st December 2034	4371	2054	7539
10	1st January 2035 - 31st December 2035	4371	2054	7539
11	1st January 2036 - 31st December 2036	4371	2054	7539
12	1st January 2037 - 31st December 2037	4371	2054	7539
13	1st January 2038 - 31st December 2038	4371	2054	7539
14	1st January 2039 - 31st December 2039	4371	2054	7539
15	1st January 2040 - 31st December 2040	4371	2054	7539

16	1st January 2041 - 31st December 2041	4371	2054	7539
17	1st January 2042 - 31st December 2042	4371	2054	7539
18	1st January 2043 - 31st December 2043	4371	2054	7539
19	1st January 2044 - 31st December 2044	4371	2054	7539
20	1st January 2045 - 31st December 2045	4371	2054	7539
21	1st January 2046 - 31st December 2046.	4371	2054	7539
22	1st January 2047 - 31st December 2047	4371	2054	7539
23	1st January 2048 - 31st December 2048	4371	2054	7539
24	1st January 2049 - 31st December 2049	4371	2054	7539
25	1st January 2050 - 31st December 2050	4371	2054	7539
26	1st January 2051 - 31st December 2051	4371	2054	7539
27	1st January 2052 - 31st December 2052	4371	2054	7539
28	1st January 2053 - 31st December 2053	4371	2054	7539
29	1st January 2054 - 31st December 2054	4371	2054	7539
30	1st January 2055 - 31st December 2055	4371	2054	7539
31	1st January 2056 - 31st December 2056	4371	2054	7539
32	1st January 2057 - 31st December 2057	4371	2054	7539
33	1st January 2058 - 31st December 2058	4371	2054	7539
34	1st January 2059 - 31st December 2059	4371	2054	7539
35	1st January 2060 - 31st December 2060	4371	2054	7539
36	1st January 2061 - 31st December 2061	4371	2054	7539
37	1st January 2062 - 31st December 2062	4371	2054	7539
38	1st January 2063 - 31st December 2063	4371	2054	7539
39	1st January 2064 - 31st December 2064	4371	2054	7539
40	1st January 2065 - 31st December 2065	4371	2054	7539
TOTAL		**1,74,830**	**82,170**	**3,01,565**

The financial projections for scenario 1 is as follows:

Year	Period	Plantation Cost in year 2026 (INR)	Output Cost (INR)	Net (INR)
0	Baseline year	0	0	-
1	1st January 2026 - 31st December 2026	12,83,88,527	96,12,379	(11,87,76,148)
2	1st January 2027 - 31st December 2027	0	96,12,379	96,12,379
3	1st January 2028 - 31st December 2028	0	96,12,379	96,12,379
4	1st January 2029 - 31st December 2029	0	96,12,379	96,12,379
5	1st January 2030 - 31st December 2030	0	96,12,379	96,12,379
6	1st January 2031 - 31st December 2031	0	96,12,379	96,12,379
7	1st January 2032 - 31st December 2032	0	96,12,379	96,12,379
8	1st January 2033 - 31st December 2033	0	96,12,379	96,12,379
9	1st January 2034 - 31st December 2034	0	96,12,379	96,12,379
10	1st January 2035 - 31st December 2035	0	96,12,379	96,12,379
11	1st January 2036 - 31st December 2036	0	96,12,379	96,12,379
12	1st January 2037 - 31st December 2037	0	96,12,379	96,12,379

13	1st January 2038 - 31st December 2038	0	96,12,379	96,12,379
14	1st January 2039 - 31st December 2039	0	96,12,379	96,12,379 (break-even achieved here)
15	1st January 2040 - 31st December 2040	0	96,12,379	96,12,379
16	1st January 2041 - 31st December 2041	0	96,12,379	96,12,379
17	1st January 2042 - 31st December 2042	0	96,12,379	96,12,379
18	1st January 2043 - 31st December 2043	0	96,12,379	96,12,379
19	1st January 2044 - 31st December 2044	0	96,12,379	96,12,379
20	1st January 2045 - 31st December 2045	0	96,12,379	96,12,379
21	1st January 2046 - 31st December 2046.	0	96,12,379	96,12,379
22	1st January 2047 - 31st December 2047	0	96,12,379	96,12,379
23	1st January 2048 - 31st December 2048	0	96,12,379	96,12,379
24	1st January 2049 - 31st December 2049	0	96,12,379	96,12,379
25	1st January 2050 - 31st December 2050	0	96,12,379	96,12,379
26	1st January 2051 - 31st December 2051	0	96,12,379	96,12,379
27	1st January 2052 - 31st December 2052	0	96,12,379	96,12,379
28	1st January 2053 - 31st December 2053	0	96,12,379	96,12,379
29	1st January 2054 - 31st December 2054	0	96,12,379	96,12,379
30	1st January 2055 - 31st December 2055	0	96,12,379	96,12,379
31	1st January 2056 - 31st December 2056	0	96,12,379	96,12,379
32	1st January 2057 - 31st December 2057	0	96,12,379	96,12,379
33	1st January 2058 - 31st December 2058	0	96,12,379	96,12,379
34	1st January 2059 - 31st December 2059	0	96,12,379	96,12,379
35	1st January 2060 - 31st December 2060	0	96,12,379	96,12,379
36	1st January 2061 - 31st December 2061	0	96,12,379	96,12,379
37	1st January 2062 - 31st December 2062	0	96,12,379	96,12,379
38	1st January 2063 - 31st December 2063	0	96,12,379	96,12,379
39	1st January 2064 - 31st December 2064	0	96,12,379	96,12,379
40	1st January 2065 - 31st December 2065	0	96,12,379	96,12,379
TOTAL		0	38,44,95,162	38,44,95,162

Scenario 2: The trees are planted in three years 2026-2028. The ERs are as follows:

Plantation Year	2026	2027	2028
Area (ha) covered under plantation	665.26	665.26	665.26

Year	Period	Biomass (tonnes)			Total Biomass (tonnes)	Total carbon (tC)	VCUs' (tCO2e)
		2026	2027	2028			
0	Baseline year	0	0	0	0	0	0
1	1st January 2026 - 31st December 2026	1457	0	0	1457	685	2513
2	1st January 2027 - 31st December 2027	1457	1457	0	2914	1370	5026
3	1st January 2028 - 31st December 2028	1457	1457	1457	4371	2054	7539
4	1st January 2029 - 31st December 2029	1457	1457	1457	4371	2054	7539
5	1st January 2030 - 31st December 2030	1457	1457	1457	4371	2054	7539
6	1st January 2031 - 31st December 2031	1457	1457	1457	4371	2054	7539
7	1st January 2032 - 31st December 2032	1457	1457	1457	4371	2054	7539
8	1st January 2033 - 31st December 2033	1457	1457	1457	4371	2054	7539
9	1st January 2034 - 31st December 2034	1457	1457	1457	4371	2054	7539
10	1st January 2035 - 31st December 2035	1457	1457	1457	4371	2054	7539
11	1st January 2036 - 31st December 2036	1457	1457	1457	4371	2054	7539
12	1st January 2037 - 31st December 2037	1457	1457	1457	4371	2054	7539
13	1st January 2038 - 31st December 2038	1457	1457	1457	4371	2054	7539
14	1st January 2039 - 31st December 2039	1457	1457	1457	4371	2054	7539
15	1st January 2040 - 31st December 2040	1457	1457	1457	4371	2054	7539
16	1st January 2041 - 31st December 2041	1457	1457	1457	4371	2054	7539
17	1st January 2042 - 31st December 2042	1457	1457	1457	4371	2054	7539
18	1st January 2043 - 31st December 2043	1457	1457	1457	4371	2054	7539
19	1st January 2044 - 31st December 2044	1457	1457	1457	4371	2054	7539
20	1st January 2045 - 31st December 2045	1457	1457	1457	4371	2054	7539

21	1st January 2046 - 31st December 2046.	1457	1457	1457	4371	2054	7539
22	1st January 2047 - 31st December 2047	1457	1457	1457	4371	2054	7539
23	1st January 2048 - 31st December 2048	1457	1457	1457	4371	2054	7539
24	1st January 2049 - 31st December 2049	1457	1457	1457	4371	2054	7539
25	1st January 2050 - 31st December 2050	1457	1457	1457	4371	2054	7539
26	1st January 2051 - 31st December 2051	1457	1457	1457	4371	2054	7539
27	1st January 2052 - 31st December 2052	1457	1457	1457	4371	2054	7539
28	1st January 2053 - 31st December 2053	1457	1457	1457	4371	2054	7539
29	1st January 2054 - 31st December 2054	1457	1457	1457	4371	2054	7539
30	1st January 2055 - 31st December 2055	1457	1457	1457	4371	2054	7539
31	1st January 2056 - 31st December 2056	1457	1457	1457	4371	2054	7539
32	1st January 2057 - 31st December 2057	1457	1457	1457	4371	2054	7539
33	1st January 2058 - 31st December 2058	1457	1457	1457	4371	2054	7539
34	1st January 2059 - 31st December 2059	1457	1457	1457	4371	2054	7539
35	1st January 2060 - 31st December 2060	1457	1457	1457	4371	2054	7539
36	1st January 2061 - 31st December 2061	1457	1457	1457	4371	2054	7539
37	1st January 2062 - 31st December 2062	1457	1457	1457	4371	2054	7539
38	1st January 2063 - 31st December 2063	1457	1457	1457	4371	2054	7539
39	1st January 2064 - 31st December 2064	1457	1457	1457	4371	2054	7539
40	1st January 2065 - 31st December 2065	1457	1457	1457	4371	2054	7539
TOTAL					**1,70,460**	**80,116**	**2,94,026**

The financial projections for scenario 2 are as follows:

Year	**Period**	**Plantation Cost in year 2026 (INR)**	**Plantation Cost in year 2027(INR)**	**Plantation Cost in year 2028(INR)**	**Output Cost (INR)**	**Net (INR)**
0	Baseline year	0	0	0	0	-
1	1st January 2026 - 31st December 2026	4,27,96,176	0	0	32,04,126	(3,95,92,049)
2	1st January 2027 - 31st December 2027	0	4,27,96,176	0	64,08,253	(3,63,87,923)

3	1st January 2028 - 31st December 2028	0	0	4,27,96,176	96,12,379	(3,31,83,797)
4	1st January 2029 - 31st December 2029	0	0	0	96,12,379	96,12,379
5	1st January 2030 - 31st December 2030	0	0	0	96,12,379	96,12,379
6	1st January 2031 - 31st December 2031	0	0	0	96,12,379	96,12,379
7	1st January 2032 - 31st December 2032	0	0	0	96,12,379	96,12,379
8	1st January 2033 - 31st December 2033	0	0	0	96,12,379	96,12,379
9	1st January 2034 - 31st December 2034	0	0	0	96,12,379	96,12,379
10	1st January 2035 - 31st December 2035	0	0	0	96,12,379	96,12,379
11	1st January 2036 - 31st December 2036	0	0	0	96,12,379	96,12,379
12	1st January 2037 - 31st December 2037	0	0	0	96,12,379	96,12,379
13	1st January 2038 - 31st December 2038	0	0	0	96,12,379	96,12,379
14	1st January 2039 - 31st December 2039	0	0	0	96,12,379	96,12,379
15	1st January 2040 - 31st December 2040	0	0	0	96,12,379	96,12,379 (Break-even achieved here)
16	1st January 2041 - 31st December 2041	0	0	0	96,12,379	96,12,379
17	1st January 2042 - 31st December 2042	0	0	0	96,12,379	96,12,379
18	1st January 2043 - 31st December 2043	0	0	0	96,12,379	96,12,379
19	1st January 2044 - 31st December 2044	0	0	0	96,12,379	96,12,379
20	1st January 2045 - 31st December 2045	0	0	0	96,12,379	96,12,379
21	1st January 2046 - 31st December 2046.	0	0	0	96,12,379	96,12,379
22	1st January 2047 - 31st December 2047	0	0	0	96,12,379	96,12,379
23	1st January 2048 - 31st December 2048	0	0	0	96,12,379	96,12,379
24	1st January 2049 - 31st December 2049	0	0	0	96,12,379	96,12,379
25	1st January 2050 - 31st December 2050	0	0	0	96,12,379	96,12,379
26	1st January 2051 - 31st December 2051	0	0	0	96,12,379	96,12,379
27	1st January 2052 - 31st December 2052	0	0	0	96,12,379	96,12,379
28	1st January 2053 - 31st December 2053	0	0	0	96,12,379	96,12,379

29	1st January 2054 - 31st December 2054	0	0	0	96,12,379	96,12,379
30	1st January 2055 - 31st December 2055	0	0	0	96,12,379	96,12,379
31	1st January 2056 - 31st December 2056	0	0	0	96,12,379	96,12,379
32	1st January 2057 - 31st December 2057	0	0	0	96,12,379	96,12,379
33	1st January 2058 - 31st December 2058	0	0	0	96,12,379	96,12,379
34	1st January 2059 - 31st December 2059	0	0	0	96,12,379	96,12,379
35	1st January 2060 - 31st December 2060	0	0	0	96,12,379	96,12,379
36	1st January 2061 - 31st December 2061	0	0	0	96,12,379	96,12,379
37	1st January 2062 - 31st December 2062	0	0	0	96,12,379	96,12,379
38	1st January 2063 - 31st December 2063	0	0	0	96,12,379	96,12,379
39	1st January 2064 - 31st December 2064	0	0	0	96,12,379	96,12,379
40	1st January 2065 - 31st December 2065	0	0	0	96,12,379	96,12,379
TOTAL		0	0	0	37,48,82,783	37,48,82,783

Conclusion

This report provides an in-depth understanding of Sikkim's potential for carbon finance projects, leveraging its unique and diverse land-use patterns. The research identifies eligible areas through RS-GIS analysis and consultations with key government officials, ensuring a focused approach to project feasibility. The findings highlight the opportunities within the AFOLU sector, including ARR, REDD+, and IFM. The integration of spatio-temporal analysis of forest degradation, land-use transitions, and identification of anthropogenic drivers has enabled precise site identification for carbon finance projects. By addressing the mandatory requirements of voluntary carbon market standards, the study lays the groundwork for feasible and impactful carbon projects.

The assessment of plantation sites for ARR carbon finance projects, based on Verra and Gold Standard criteria, shows the importance of having accurate data and careful selection of sites. Using RS GIS analysis, sites that remained barren or agricultural over a 10-year period were identified for inclusion in ARR projects. RS data was utilized to extract sites within the RFA that were classified as non-forest and showed consistent degradation between 2013 and 2023. Further refinement of non-forest sites was carried out based on elevation. Based on the analysis of barren and agricultural land, approximately 470 hectares in Sikkim have been identified as potential areas for ARR projects. Among these, four ranges—Chungthang, Gangtok, Namchi, and Namthang—have the highest potential for ARR implementation in terms having maximum non-forest land for the 10 years.

The Forest and Environment Department of Sikkim provided information for 1,152 plantation sites established under schemes like MRMS, CAMPA, and other conservation initiatives. However, CAMPA sites were excluded as they are meant for compensatory plantations. Out of the 1,152 sites, only 6 MRMS plantation sites met the eligibility criteria for ARR carbon finance projects. These results highlight the need for robust baseline data and more careful site selection to ensure compliance for such projects. This is a valuable learning step toward improving processes and making future ARR projects more successful.

The analysis of forest ranges and protected area degradation in Sikkim was performed to identify the sites suitable for REDD/REDD+ projects. Sikkim's forest ranges, covering 4,927.08 sq. km (69.45% of the state's geographic area), demonstrate varying levels of degradation, with seven ranges showing a consistent rise in degradation since 2013. These ranges occupy 1,233.75 sq. km (25.04% of the forest area). Similarly, Sikkim's protected areas, spanning 2,167.17 sq. km (30.54% of the state's land), have also experienced increased degradation, particularly in the Barsey Rhododendron Sanctuary, Khangchendzonga National Park, and Kyongnosla Alpine Sanctuary, which collectively account for 87.33% of the total protected area.

This study identified six key drivers of forest degradation in Sikkim through RS-GIS analysis, stakeholder consultations, newspaper articles, and an extensive literature review: forest fires, population growth, resource dependency, shifting cultivation, developmental pressures, and unsustainable tourism. Forest fires pose a significant threat, particularly in 16 forest ranges and three protected areas, with the southern districts like Gangtok, Gyalsing, Namchi, Pakyong, and Soreng being the most affected. Population growth, projected to reach 6.8 lakh by 2030, has increased pressure on forests, especially in 18 forest ranges and three protected areas. In high-altitude regions such as the Barsey-Singalila area, heavy reliance on forest resources for fuelwood, livestock, and construction adds to the strain. Although shifting cultivation has been largely phased out, remnants of the practice persist in places like Dzongu Valley, contributing to land degradation and encroachment. Infrastructure development has further accelerated forest conversion to meet agricultural demands. Unsustainable tourism also exerts immense pressure on the environment, with the East district, followed by the South, and West districts facing the highest impacts from overcrowding and overuse of natural sites. The further cause-and-effect analysis identifies three forest ranges and one protected area where forest fires and population growth are the major causes of degradation, highlighting the need for sustainable development strategies to preserve Sikkim's ecological integrity.

To stop further forest degradation, it is important to tackle the main causes, improve monitoring, and promote sustainable land management. Protecting Sikkim's forests and reducing the effects of climate change will require combined efforts and strong collaboration.

Annexures

I. Agenda for the Workshop/ Consultation

ReNew teri

Developing Carbon Financing Mechanism for Forestry Sector in Sikkim

Workshop Agenda

Date: *11th September 2024 (Wednesday)*

Venue: *Forest & Environment Department, Gangtok, Sikkim*

1000 hrs – 1015 hrs	Welcome Address - Introduction about TERI and Renew - Theme Setting (Objective of the project and workshop, progress and timelines)
1015 hrs – 1030 hrs	Remarks by the Chair, Sikkim Forest Department (Expectations from the project and this workshop)
1030 hrs – 1100 hrs	Introduction to Carbon Financing in Forestry (ARR, REDD+, IFM, WRC)
1100 hrs – 1130 hrs	Process of Project Development and State Preparedness
1130 hrs – 1200 hrs	Discussion on Feasibility Assessment and Project Suitability
1200 hrs – 1230 hrs	Possible Areas of Intervention in Sikkim (Discussion) Conservation efforts, Plantation Drives/ Plantations in past 2 years, Further support required from Sikkim FED
1230 hrs – 1300 hrs	Use of blockchain in carbon credits by Mr. Kshitij Saxena, DFO Gyalshing
End of the workshop	

II. Attendance Sheet of the Workshop/ Consultation

ReNew

teri

Developing Carbon Financing Mechanism for Forestry Sector in Sikkim

Date: 11th to 12th September 2024

Venue:

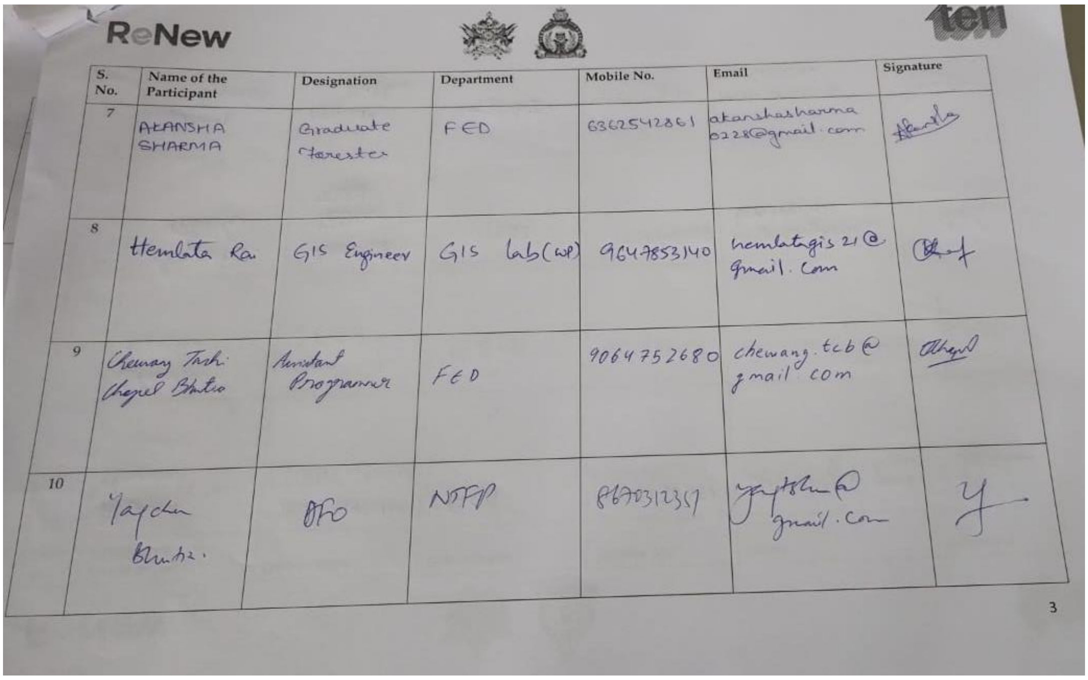
Attendance Sheet

S. No.	Name of the Participant	Designation	Department	Mobile No.	Email	Signature
1	PRADEEP Kumar	SECRETARY		[illegible]	[illegible]@gmail.com	
2	D. Manjunatha	CCF (T/WL)	SFD	9451387735	manjunatha502@yahoo.com	

ReNew

teri

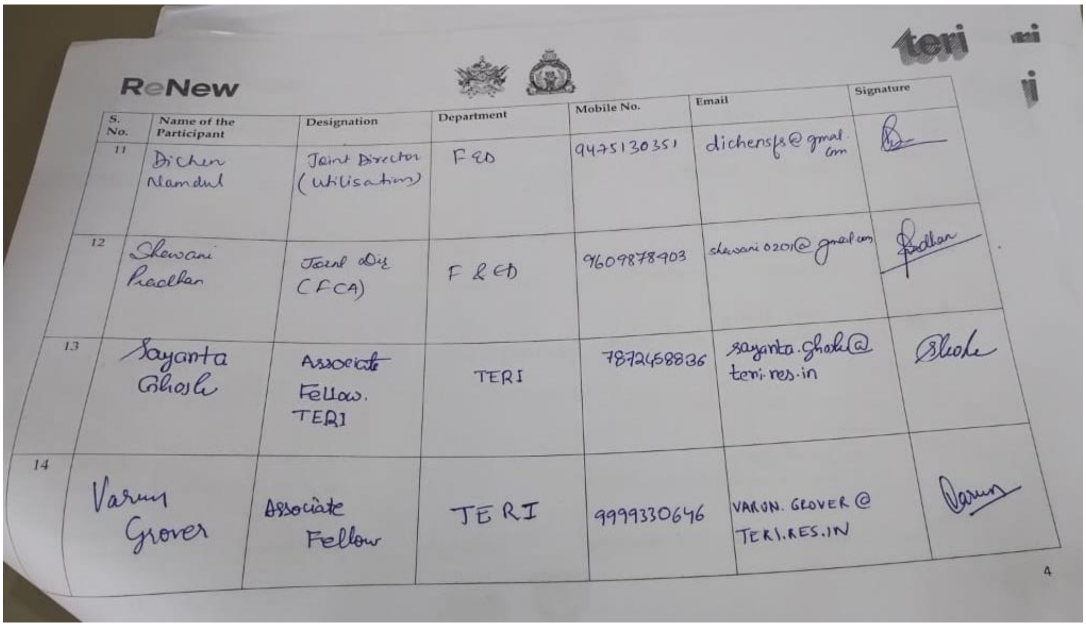
S. No.	Name of the Participant	Designation	Department	Mobile No.	Email	Signature
3	Karma Legshey	CCF	Forest & Env.	9434127778	[illegible]@yahoo.co.in	11/09/24
4	B.B. Gurung	CF	"	9733003990	[illegible]@gmail.com	
5	Merab Basnet	DFO (WP)	F&ED.	9593378085	dfowpsikkim2015@gmail.com	
6	Anjali Sharma	JTO (WP)	F&ED.	7001353233	[illegible]@gmail.com	



ReNew teri

S. No.	Name of the Participant	Designation	Department	Mobile No.	Email	Signature
7	AKANSHA SHARMA	Graduate Forester	FED	6362542861	akanshasharma0228@gmail.com	[signature]
8	Hemlata Rai	GIS Engineer	GIS lab(WP)	9647853140	hemlatagis21@gmail.com	[signature]
9	Chewang Tashi Chopel Bhutia	Assistant Programmer	FED	9064752680	chewang.tcb@gmail.com	[signature]
10	Yaychen Bhutia	BFO	NTFP	8670312357	[illegible]@gmail.com	[signature]

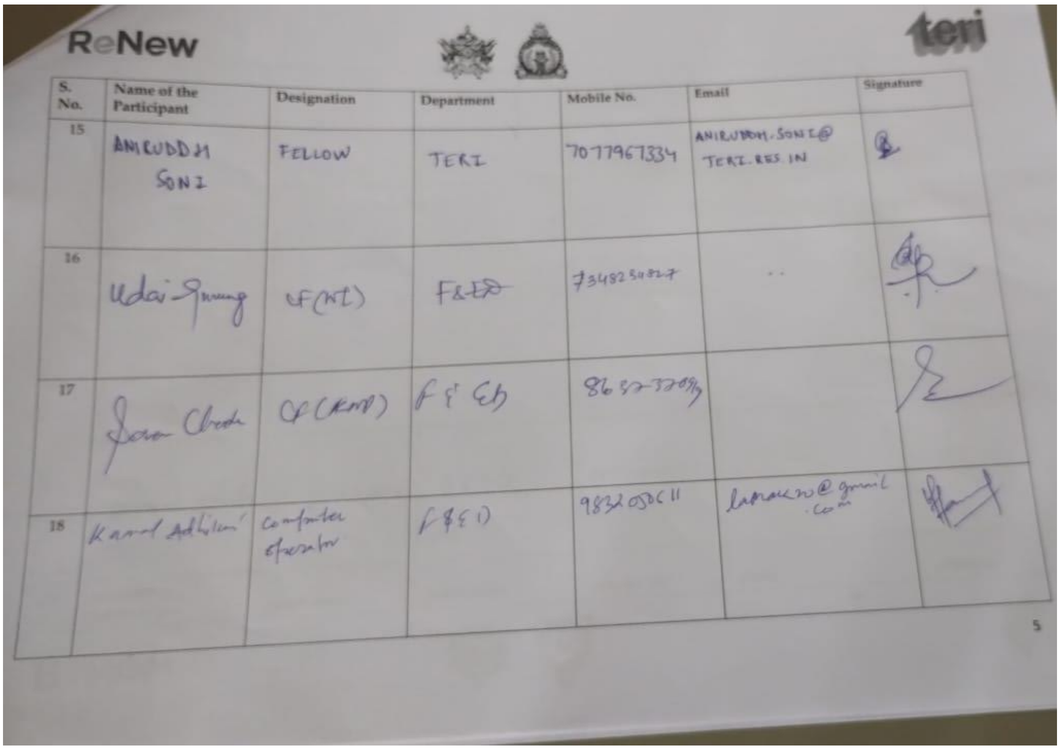
3



ReNew teri

S. No.	Name of the Participant	Designation	Department	Mobile No.	Email	Signature
11	Dichen Namdul	Joint Director (Utilisation)	FED	9475130351	dichensfs@gmail.com	[signature]
12	Shewani Pradhan	Joint Dir (CFCA)	F&ED	9609878903	shewani0201@gmail.com	[signature]
13	Sayanta Ghosh	Associate Fellow. TERI	TERI	7872458836	sayanta.ghosh@teri.res.in	[signature]
14	Varun Grover	Associate Fellow	TERI	9999330646	VARUN.GROVER@TERI.RES.IN	[signature]

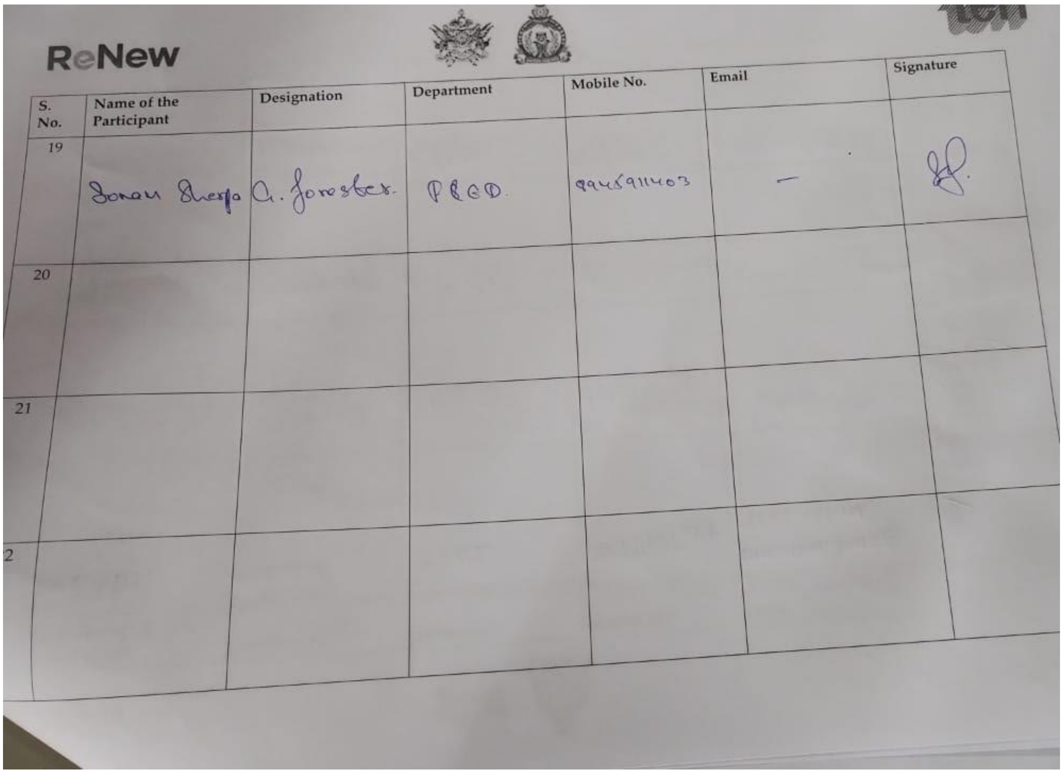
4



ReNew teri

S. No.	Name of the Participant	Designation	Department	Mobile No.	Email	Signature
15	ANIRUDDH SONI	FELLOW	TERI	7077967334	ANIRUDDH.SONI@TERI.RES.IN	[illegible]
16	Udai Gurung	CF (NT)	F&ED	7348250827	..	[illegible]
17	[illegible]	CF (KMP)	F & ED	8637370917		[illegible]
18	Kamal Adhikari	Computer Operator	F&ED	9832050611	[illegible]@gmail.com	[illegible]

5



ReNew teri

S. No.	Name of the Participant	Designation	Department	Mobile No.	Email	Signature
19	Sonam Sherpa	A. Forester	F&ED	9945911403	—	[illegible]
20						
21						
2						

III. Government of India Submission to UNFCCC

Government of India Submission to UNFCCC to Revise Country Forest Definition for CDM A/R Projects

In the light of several changes proposed for determining the eligibility of land for CDM A/R Projects {EB 22 (Annex 16) through EB26 (Annex 18) which was later put on hold by the COP12/MOP2}, and EB35 Annex18, India, considering its national circumstances feels that it needs to revise its definition of CDM forest communicated earlier to CDM EB by the DNA in respect of CDM A/R Projects.

Taking into account practical considerations of the national circumstances, the Government of India proposes following revised country definition of CDM forest:

Tree crown cover value between 10 and 30%:15% or equivalent stocking level

Land area value between 0.05 and 1 hectare: 0.05 ha

Tree height value between 2 and 5 meters: 2 meters

****

Screenshot below of the original email from the DNA, India:

"R.K.Sethi" <rksethi@nic.in>
Sent by: rksethi@nic.in

07/07/2008 13:32

To: Neeta Hooda <NHooda@unfccc.int>
cc: Sudhir Sharma <SSharma@unfccc.int>, Wojciech Galinski <WGalinski@unfccc.int>, Kay Merce <KMerce@unfccc.int
Subject: Re: Change in definition of Forest for CDM A/R project activities

```
Dear Ms Hooda

Thanks for your mail. The Government of India agrees that you may drop the
word 'Equivalent Stocking Level' from our revised country definition
regarding CDM A&R Projects. Only the value as mentioned may remain under the
"tree crown cover value".

With best regards
Rajesh Sethi
```

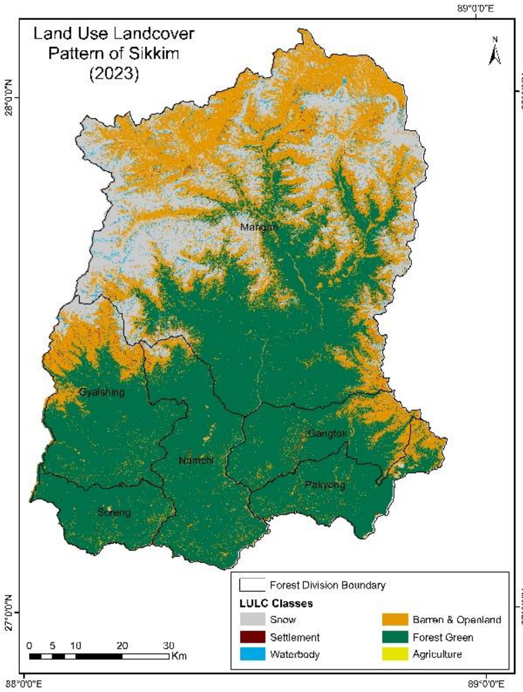
IV. Comparison with High Resolution Data

Land use Landcover:

A Land Use and Land Cover (LULC) analysis for Sikkim was conducted for 2023 using both Landsat 8 (30m resolution) and Sentinel 2 (10m resolution) imagery to evaluate classification accuracy. The comparison of area statistics revealed minimal differences between the LULC class areas from Landsat 8 and Sentinel 2, with Sentinel 2 generally reporting slightly higher areas for most classes, except for Snow and Forest Green. The area for Forest Green was almost identical in both datasets, while Snow showed a small discrepancy of 37.25 sq. km. and forests a negligible 0.28 sq. km. Minor differences were also observed in Waterbody, Settlement, and Agriculture classes. However, Barren and Open land showed a difference of 24.78 sq. km. Despite these small differences, no LULC class had a percentage area difference exceeding 0.6%, emphasizing the classification's robustness. This similarity in area measurements indicates that the moderate-resolution Landsat 8 classification is closely aligned with the high-resolution Sentinel 2 classification, highlighting the accuracy of the Landsat 8-based analysis and its reliability for further studies.

		Land Use Landcover Analysis For 2023			
S.no.	Class	Landsat 8 (sq. km.)	Sentinel 2 (sq. km.)	Difference (sq. km.)	Difference (%)
1	Snow	1315.78	1278.53	37.25	0.52
2	Settlement	43.79	47.46	3.67	0.05

		Land Use Landcover Analysis For 2023			
3	Waterbody	130.58	132.54	1.96	0.03
4	Barren & Open land	1942.98	1967.76	24.78	0.35
5	Forest Green	3645.70	3645.98	0.28	0.00
6	Agriculture	19.51	26.10	6.59	0.09



For the correlative assessment, reference points were generated using a stratified random sampling method and overlaid on a 10m Sentinel-2 classified FVC image to evaluate the accuracy of forest density classification derived from 30m Landsat 8 data. To assess the reliability of the classification, an error matrix (also referred to as a confusion matrix or contingency matrix) was constructed.

The results of the correlative evaluation of the LULC analysis between Sentinel-2 and Landsat 8 for the year 2023 are summarized in the table below:

FVC Correlative Assessment 2023		
	2023	
Class	**User Accuracy**	**Producer Accuracy**
Snow	95.2381	80
Settlement	70	87.5
Waterbody	83.3333	100
Barren & Open land	90	87.0968
Forest Green	96.2264	96.2264
Agriculture	71.4286	100

Correlative Assessment with Error Matrix – 2023	2023	
	Kappa Coefficient = 0.86	
	Overall Accuracy = 90.5%	
Class	Commission Error %	Omission Error %
Snow	4.7619	20
Settlement	30	12.5
Waterbody	16.6667	0
Barren & open land	10	12.9032
Forest Green	3.7736	3.7736
Agriculture	28.5714	0

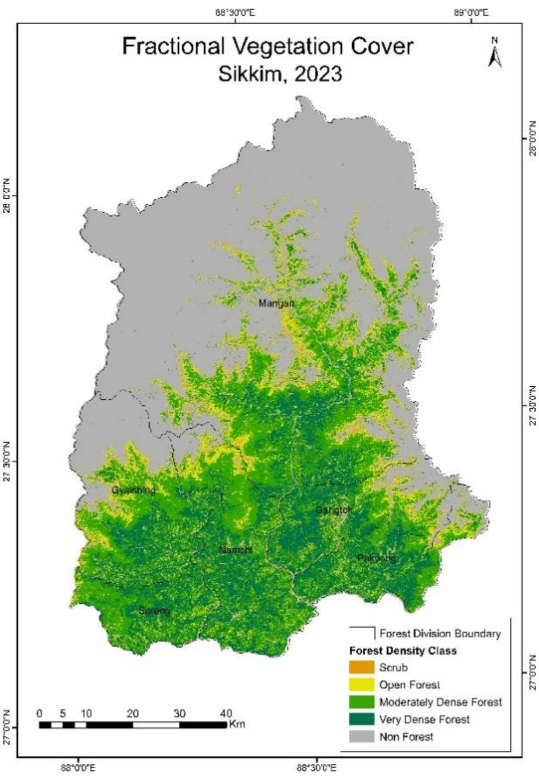
Fractional Vegetation Cover:

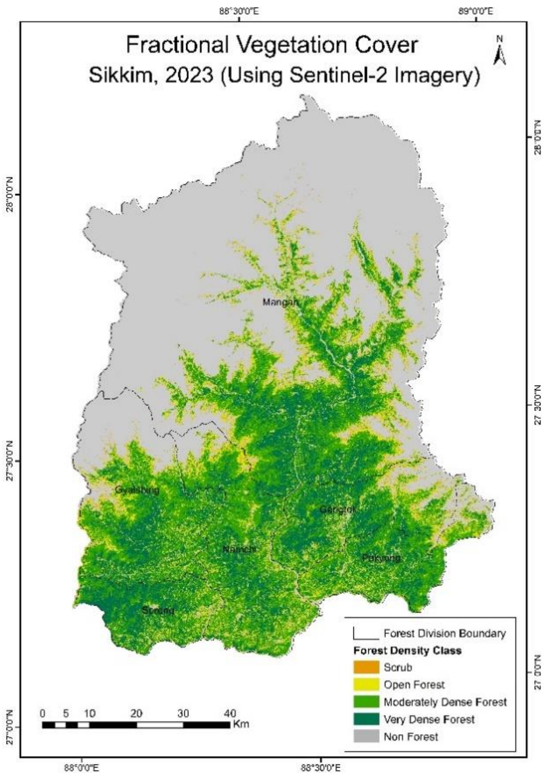
The Fractional Vegetation Cover (FVC) analysis was conducted using Sentinel-2 imagery from the same season as the Landsat 8 imagery. The final forest cover results from both Landsat and Sentinel-2 were then compared. It was observed that the forest cover values derived from Landsat closely aligned with those obtained from the FVC analysis on Sentinel-2 imagery.

To understand better, the visual and statistical comparison have been incorporated below:

Value	Class	2023 (Landsat 8)	2023 (Sentinel 2)	Difference in Area (%)
		Area (In Sq Km)	Area (In Sq Km)	
1	Scrub	135.26	154.00	0.26
2	Open Forest	597.20	617.44	0.28
3	Moderately Dense Forest	1789.57	1737.01	0.74
4	Very Dense Forest	1100.28	1120.51	0.28
6	Non-Forest	3481.70	3477.29	0.06
Total		7101.53	7101.54	-

Analysis of each class revealed that none exhibited values that deviated by more than 1 percent of the state's total area. This consistency shows a high level of accuracy in the results, confirming the reliability of the classification across the different datasets used. This comparison between Landsat and Sentinel data confirmed the accuracy of the Landsat-based findings, validating the results and ensuring their reliability.





For the correlative assessment, reference points were plotted using stratified random sampling method and overlain on 10m Sentinel 2 classified FVC image for estimating the precision in forest density classification done using 30m Landsat 8 data. An error matrix (also known as confusion matrix or contingency matrix) was prepared to highlight the authenticity of classification.

The correlative evaluation of the Forest Density analysis between Sentinel 2 and Landsat8 conducted for the year 2023 are presented in the table below:

FVC Correlative Assessment 2023		
	2023	
Class	**User Accuracy**	**Producer Accuracy**
Scrub	80	80
Open Forest	80	80
Moderately Dense Forest	90.91	83.33
Very Dense Forest	85.71	85.71
Non-Forest	95.45	100

Correlative Assessment with Error Matrix – 2023	**2023**	
	Kappa Coefficient = 0.86	
	Overall Accuracy = 90%	
Class	**Commission (%)**	**Omission (%)**
Scrub	20	20
Open Forest	20	20
Moderately Dense Forest	9.09	16.67
Very Dense Forest	14.29	14.29
Non-Forest	4.55	0

V. List of Species for Plantation in Sikkim

Sl. No.	Common Name	Scientific Name	Type of species
1	Ambakey	*Quercus leucotrichophora*	Fruit
2	Kafal	*Myrica esculenta*	Fruit
3	Phamphal	*Persa americana*	Fruit
4	Nebara	*Ficus hookeri*	Fruit
5	Asarey	*Viburnum cordifolium*	Fruit
6	Gagun	*Saurauia nepalensis*	Fruit
7	Bhadrasey	*Elaeocarpus sikkimensis*	Fruit
8	Lopsi	*Spondias axillaris*	Fruit
9	Omphi	*Pyrularia edulis*	Fruit
10	Local Cherry	*Prunus cerasoides*	Fruit
11	Mushurey Katush	*Castanopsis hystrix*	Fruit
12	Ghurpish	*Leucosceptrum canum*	Fruit
13	Siltimbur	*Litsea cubeba*	Medicinal
14	Khanakpa	*Evodia meliaefolia*	Medicinal
15	Lakuri	*Araucaria bindrabunensis*	Medicinal
16	Saur	*Betula alnoides*	Medicinal
17	Falado	*Erythrina indica*	Medicinal
18	Kharaney	*Symplocos theifolia*	Medicinal
19	Pepli	*Symingtonia populnea*	Medicinal
20	Malata	*Macaranga pustulata*	Medicinal
21	Jhuguney	*Eurya japonica*	Commercial
22	Local Chandan/Rakht Chandan	*Pterocarpus santalinus*	Commercial
23	Kapasey	*Acer campbellii*	Commercial
24	Arupatey	*Prunus napaulensis*	Commercial
25	Malatha	*Macaranga nepalensis*	Commercial
26	Lake Chilauney	*Schima wallichii*	Commercial
27	Tooni	*Toona ciliata*	Commercial
28	Uttish	*Alnus nepalensis*	Commercial
29	Panisaj	*Terminalia myriocarpa*	Commercial

VI. References

1. *A. J. Dougill, J. G. Soussan, E. Kiff et al., "Impacts of community forestry on farming system sustainability in the middle hills of Nepal," Land Degradation & Development, vol. 12, no. 3, pp. 261–276, 2001.*
2. *Bhuyan, R. 2019. A review note on shifting cultivation in northeast India amidst changing perception. Dhaulagiri Journal of Sociology and Anthropology, 13: 90–95*
3. *Bond, W. J., and J. E. Keeley (2005), Fire as a global 'herbivore': The ecology and evolution of flammable ecosystems, Trends Ecol. Evol., 20(7), 387–394.*
4. *Bowman, D., et al. (2009), Fire in the Earth System, Science, 324(5926), 481–484.*
5. *Castella, J. C., G. Lestrelin, C. Hett, J. Bourgoin, Y. R. Fitriana, A. Heinimann, and J. L. Pfund. 2013. Effects of landscape segregation on livelihood vulnerability: moving from extensive shifting cultivation to rotational agriculture and natural forests in northern Laos. Human Ecology, 41(1): 63–76*
6. *Center for International Earth Science Information Network - CIESIN - Columbia University. 2018. Gridded Population of the World, Version 4 (GPWv4): Population Count, Revision 11. Palisades, New York: NASA Socioeconomic Data and Applications Center (SEDAC).*
7. *Chettri, S. K., Sharma, G., Gaira, K. S., Pandey, A., Joshi, R., Chettri, N., & Pradhan, B. K. (2021). Forest resource use pattern in fringe villages of barsey Rhododendron sanctuary and singalila national park of khangchendzonga landscape, India. International Journal of Forestry Research, 2021(1), 8856988.*
8. *Chhetri, M. (2019). Traditional Energy Use Practices in the Eastern Himalayas: A Focus on Sikkim. Journal of Mountain Ecology, 45(2), 56–67.*
9. *Chouhan, R., Rao, N., 2011. Vegetation detection in multispectral remote sensing images: protective role-analysis of coastal vegetation in 2004 Indian Ocean Tsunami. Geo-Information for disaster management, Turkey.*
10. *D. K. Langat, E. K. Maranga, A. A. Aboud, and J. K. Cheboiwo, "Role of forest resources to local livelihoods: the case of East Mau Forest ecosystem, Kenya," International Journal of Forestry Research, vol. 2016, Article ID 4537354, 10 pages, 2016.*
11. *D. N. Tiwari, Report of the Task Force on Conservation and Sustainable Use of Medicinal Plants, Government of India Planning Commission, New Delhi, India, 2000.*

12. *Dam, S. (2020). Status of sustainable tourism practices in Sikkim, India: Use of select relevant parameters to assess issues and challenges. International Journal of Tourism & Hotel Business Management, 2(4), 331–350.*
13. *DeFries, R. S., M. C. Hansen, and J. R. G. Townshend, 2000. Global continuous fields of vegetation characteristics: A linear mixture model applied to multi-year 8km AVHRR data. Int. J. Remote Sens., 21, 1389–1414.*
14. *Encyclopaedia Britannica. (n.d.). Kanchenjunga. Encyclopaedia Britannica. Retrieved from https://www.britannica.com/place/Kanchenjunga*
15. *FAO. (2016). Forestry Remote Sensing. Food and Agriculture Organization of the United Nations.*
16. *Forest and Environment Department. (2007). Introduction. State of Environment 2007 – Sikkim http://sikkimforest.gov.in/soer/Introduction.pdf*
17. *Gao, Y.N., Gao, J.F., Wang, J., Wang, S.S., Li, Q., Zhai, S.H., Zhou, Y., 2017. Estimating the biomass of unevenly distributed aquatic vegetation in a lake using the normalized water-adjusted vegetation index and scale transformation method. Sci. Total Environ., 601, 998–1007.*
18. *Gitelson, A.A., Kaufman, Y.J., Stark, R., Rundquist, D., 2002. Novel algorithms for remote estimation of vegetation fraction. Remote Sens. Environ., 80, 76–87.*
19. *Government of Sikkim. (n.d.). About Sikkim. Government of Sikkim. Retrieved from https://www.sikkim.gov.in/portalcontent/about-sikkim#:~:text=About%20Sikkim,-Sikkim%20is%20a&text=It%20borders%20Tibet%20in%20the,West%20Bengal%20in%20the%20south*
20. *Government of Sikkim. (n.d.). Before you travel. Government of Sikkim. Retrieved from https://sikkim.gov.in/department/departmentmenudetails?url=Menu%3Dtourism-civil-aviation-department%2Fbefore-you-travel*
21. *Government of Sikkim. (n.d.). Forest department. Government of Sikkim. Retrieved from http://sikkimforest.gov.in/forest.htm*
22. *Government of Sikkim. (n.d.). Geography of Sikkim. Government of Sikkim. Retrieved from https://www.sikkim.gov.in/department/departmentmenudetails?url=Menu%3Dtourism-civil-aviationdepartment%2Fgeography#:~:text=Sikkim%20is%20a%20land%20of,has%20within%20its%207%2C096%20sq*
23. *Gupta, R., Haider, L. J. Haider, and H. Österblom. 2020. The theory of cross-scale interactions: an illustration from remote villages in Sikkim, India. Environment, Development and Sustainability, 22(4), 3777–3804.*
24. *Gutman, G., and A. Ignatov, 1998. The derivation of the green vegetation fraction from NOAA/ AVHRR data for use in numerical weather prediction models. Int. J. Remote Sens., 19, 1533–1543.*

25. Harris, N.L., et al., 2012. Baseline map of carbon emissions from deforestation in tropical regions. Science, 336(6088), pp.1573-1576.

https://www.ipcc.ch/site/assets/uploads/2018/03/GPG_LULUCF_FULLEN.pdf

26. India State of Forest Report (ISFR), 2011 to 2021, Forest Survey of India, Dehradun, https://fsi.nic.in/

27. Indian Bureau of Mines. (2012). Indian mineral yearbook 2012: Sikkim. https://www.ibm.gov.in/writereaddata/files/07092014124541IMYB_2012_11_24%20SIKKIM.pdf

28. IPCC, 2006. Guidelines for National Greenhouse Gas Inventories

29. IPCC. (2003). Good Practice Guidance for Land Use, Land-Use Change, and Forestry. Intergovernmental Panel on Climate Change.

30. Jiang, Z., Huete, A.R., Chen, J., Chen, Y., Li, J., Yan, G., Zhang, X., 2006. Analysis of NDVI and scaled difference vegetation index retrievals of vegetation fraction. Remote Sens. Environ. 101, 366–378.

31. Jin, S., & Sader, S. A. (2005). Comparison of time series tasseled cap wetness and the normalized difference moisture index in detecting forest disturbances. Remote sensing of Environment, 94(3), 364-372.

32. Karaburun, A., 2010. Estimation of C factor for soil erosion modeling using NDVI in Buyukcekmece watershed. Ozean journal of applied sciences, 3, pp.77-85.

33. Lepcha, P. Y and S. Khaling. 2020. Agriculture and Food Systems of Dzongu: From 'We Eat What We Grow' to 'We Eat What We Buy'. The Confluence Collective. Details available at https://www.theconfluencecollective.com/blog/agriculture-and-food-systems-of-dzongu-from-we-eat-what-we-grow-to-we-eat-what-we-buy

34. Lepcha, P. Y., & Khaling, S. (2022). Shifting to settled agriculture: Experiences from Dzongu Valley, North Sikkim, India. In A Tradition in Transition: Understanding the Role of Shifting Cultivation for Sustainable Development of Northeast India (pp. 246–271). The Energy and Resources Institute (TERI).

35. M. Junaid Jazib, "Forest dependence and the utilization patterns of locals in the PirPanjal Himalayas," Civil and Environmental Research, vol. 7, no. 1, pp. 78–83, 2015

36. M. Sundriyal and R. C. Sundriyal, "Underutilized edible plants of the Sikkim Himalaya: need for domestication," Current Science, vol. 85, no. 6, pp. 731–736, 2003.

37. Maas, S. J., 2000. Linear mixture modeling approach for estimating cotton canopy ground cover using satellite multispectral imagery. Remote Sens. Environ., 72, 304–308.

38. Matricardi, E. A., Skole, D. L., Pedlowski, M. A., Chomentowski, W., & Fernandes, L. C. (2010). Assessment of tropical forest degradation by selective logging and fire using Landsat imagery. Remote Sensing of Environment, 114(5), 1117-1129.

39. *McDuie-Ra, D., & Chettri, M. (2020). Concreting the frontier: Modernity and its entanglements in Sikkim, India. Political Geography, 76, 102089. https://doi.org/10.1016/j.polgeo.2019.102089*
40. *Ministry of Environment, Forest and Climate Change (MoEFCC). (2018). State of Forests in India: A Report on Biomass and Energy Use in Mountain Regions. Government of India.*
41. *Ministry of Statistics and Programme Implementation. (2007). Sikkim state report. https://mospi.gov.in/sites/default/files/publication_reports/nad10_2007_sikkimreport_final.pdf*
42. *Mupfiga, U.N.; Mutanga, O.; Dube, T.; Kowe, P. Spatial Clustering of Vegetation Fire Intensity Using MODIS Satellite Data. Atmosphere 2022, 13, 1972.*
43. *N. Senthilkumar, S. P. (2014). Revisiting forest types of India (Champion and Seth, 1968): A case study on Myristica. International Journal of Advanced Research (2014), Volume 2, Issue 2 , 492-501.*
44. *Neopaney, Y., Ghose, M. K., & Paul, S. (2016). Survey paper on Effect of Urban Sprawling on Deforestation and Encroachment of Land using RS and GIS-A Case Study of Gangtok City. International Journal of Computer Applications, 133(4), 40-42.*
45. *P. Kandel, N. Chettri, R. P. Chaudhary et al., "Plant diversity of the Kangchenjunga Landscape, Eastern Himalayas," Plant Diversity, vol. 41, no. 3, pp. 153–165, 2019*
46. *Pandya, M. R., & Pathak, V. (2021). Algorithm Theoretical Basis Document (ATBD) of Vegetation Indices (NDVI, EVI) and Vegetation Fraction Retrieval from OCM-3 payload onboard Oceansat-3.*
47. *Qi, J., A. Chehbouni, A. R. Huete, and Y. Kerr, 1994. A modified soil adjusted vegetation index (MSAVI). Remote Sens. Environ., 48, 119–126.*
48. *Rai, S., & Gurung, D. (2020). Energy Challenges in Sikkim: A Socio-Economic and Environmental Perspective. International Journal of Energy Studies, 38(1), 89–102.*
49. *Ramachandra, T.V., Kumar, U., 2004. Geographic resources decision support system for land use land cover dynamics analysis. In proceedings of the FOSS/GRASS users conference, Bangkok, Thailand, pp. 12-14.*
50. *Rao, P., & Prakash, A. (2015). Biomass Dependency and Energy Consumption Patterns in High-Altitude Villages of India. Energy and Environment Journal, 32(4), 241–259.*
51. *Rasul, G. and G. B. Thapa. 2003. Shifting cultivation in the mountains of South and Southeast Asia: regional patterns and factors influencing the change. Land Degradation & Development, 14(5): 495–508*
52. *S. Rayamajhi, Forest dependency, livelihoods and conservation of high-altitude forests in Nepal, Ph.D. thesis, University of Copenhagen, Copenhagen, Denmark, 2010.*

53. *Saatchi, S.S., Harris, N.L., Brown, S., et al. (2011). Benchmark map of forest carbon stocks in tropical regions across three continents. Proceedings of the National Academy of Sciences, 108(24), 9899-9904.*
54. *Sharma, R., et al. (2018). Impact of Biomass Consumption on Himalayan Forests. Mountain Research and Development, 37(3), 302–311.*
55. *Sikkim Energy and Forest Report. (2020). Annual Report on Energy Use and Forest Conservation in Sikkim. Department of Energy and Forests, Government of Sikkim.*
56. *Sikkim Tourism. (2020). History. Sikkim Tourism. https://sikkimtourism.gov.in/Public/ExperienceSikkim/history*
57. *Sikkim Tourism. (n.d.). Weather and climate. Sikkim Tourism https://sikkimtourism.gov.in/Public/Planning/weatherandclimate*
58. *Townshend, J. R. G., 1999. MODIS enhanced land cover and land cover change product: Algorithm theoretical basis documents (ATBD), version 2.0. pp. 92.*
59. *United Nations Framework Convention on Climate Change. (n.d.). [Title of the document]. UNFCCC.https://cdm.unfccc.int/UserManagement/FileStorage/THNRJC15IW4K89UBE6DFZYX23OVP0Q.*
60. *United Nations Framework Convention on Climate Change. (n.d.). REDD+ workstreams. UNFCCC. https://unfccc.int/topics/land-use/workstreams/reddplus*
61. *Veraverbeke, S., B. Rogers, and J. Randerson (2015), Daily burned area and carbon emissions from boreal fires in Alaska, Biogeosciences, 12(11), 3579–3601*
62. *Wilson, E. H., & Sader, S. A. (2002). Detection of forest harvest type using multiple dates of Landsat TM imagery. Remote Sensing of Environment, 80(3), 385-396.*
63. *WRI, 2005. The Greenhouse Gas Protocol for Project Accounting: Guidelines for Quantifying GHG Reductions from Projects. World Resources Institute.*
64. *Xie, Y., Zhao, X., Li, L., & Wang, H., 2010. Calculating NDVI for landsat7 etm data after atmospheric correction using 6s model: a case study in Zhangye City, China. In proceeding IEEE geoinformatics18th international conference on digital object identifier, pp.1-4.*
65. *Zeng, X., R. E. Dickinson, A. Walker, and M. Shaikh, 2000. Derivation and evaluation of global 1-km fractional vegetation cover data for land modeling. J. Appl. Meteor., 39, 826–839.*