

Land Use Land Cover Change Impact on Carbon Storage and Sequestration in Ranthambhore Tiger Reserve

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The accumulation of CO₂ in the atmosphere due to fossil fuel use, deforestation, and other anthropogenic sources is changing the global climate. Carbon emissions from tropical deforestation have long been recognized as a key component of the global carbon budget, and more recently of our global climate system. The Intergovernmental Panel on Climate Change (IPCC) estimated that 1.86 billion tons of carbon is released annually due to LULC change, of which the major part is tropical deforestation, and it is a major source of carbon emissions and an active contributor to global warming. Agriculture expansion due to increasing population has been regarded as one of the primary causes of LULC change / deforestation and a major source of carbon emissions from terrestrial ecosystems. The main objective of this study is to investigate the possible effects of LULC change and increasing CO₂ concentration on the carbon storage potential of the Ranthambhore tiger reserve. For this purpose, Esri ArcGIS-10x based InVEST 3.9.0 Carbon Model has been used to estimate the carbon stock in the Ranthambhore tiger reserve. The forest area in Ranthambhore tiger reserve is 529.48 Km² in 1991, 510.03 Km² in 2001, 462.64 Km² in 2011, and 406.48 Km² in 2021, which is continuously decreasing. Subsequently, carbon storage and sequestration have also decreased from 32.35 (Million Kg / Ha) in 1991 to 24.36 (Million Kg / Ha) in 2021. Carbon storage and sequestration are decreased 7.99 Million Kg / Ha in the last three decades. These changes in forest area can be primarily attributed to human activities at a large scale (tourism) and deforestation in the Ranthambhore tiger reserve.

Introduction

The state of terrestrial ecosystems in the present day is a product of past climate and anthropogenic land cover change (Pongratz et al., 2009; Strassmann et al., 2008). Many processes in the terrestrial biosphere operate

on centennial to millennial timescales including the growth and development of forests and the dynamics of soil organic matter decomposition (Trumbore, 2000; Canadell et al., 2007). Although there is evidence that even old trees continue to accumulate carbon at a steady rate (Luyssaert et al., 2008), forests tend to be most productive during their early stages of growth; as a forest ecosystem matures, the rate at which it sequesters carbon tends to decrease (Albani et al., 2006) and net ecosystem production approaches zero (Canadell et al., 2007). Thus, the potential for carbon to be stored in terrestrial ecosystems in the future depends strongly on past ecosystem history and the trajectory of ecosystems at present (Magnani et al., 2007).

About the Study Area

The study area is the Ranthambhore tiger reserve, which is located at Sawai Madhopur district of western Rajasthan, and the junction of the Aravalli and the Vindhyan mountain ranges (Figure 1). The Ranthambhore tiger reserves spread over 1394.48 Km², out of which 666.92 Km² is a reserve forest, 726.81 Km² is protected forest, and 0.75 Km² is unclassed forest. The Ranthambhore tiger reserve is divided into almost two equal parts by the river Banas. The area south-west of Banas having Ranthambhore national park, Sawai Madhopur Sanctuary, Sawai Mansingh Sanctuary, and Qualji closed area constitutes the core division of the Ranthambhore tiger reserve with HQ at Sawai Madhopur. The national park area is considered as the core area of the tiger reserve and the adjoining forest areas and the sanctuaries are treated as the buffer for the core. North-east of Banas having Keladevi sanctuary constitutes the buffer division, with HQ at Karauli. The Keladevi Sanctuary also acts as a buffer for the Ranthambhore national park (core area).

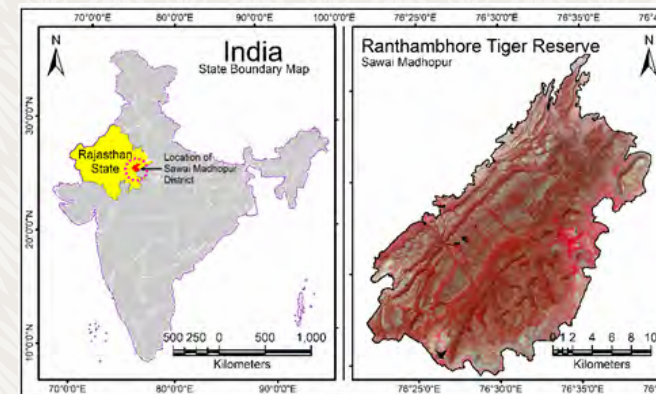


Figure 1. Location Map of the Study Area

Data Used and Methodology

Landsat satellite imageries of years 1991, 2001, 2011, and 2021 have been downloaded from Earth Explorer, USGS: <https://earthexplorer.usgs.gov>. The detail of these datasets with satellite name, sensor type, spatial resolution, and acquisition date is given below.

- Landsat-5 TM (30 m spatial resolution): 14th March 1991
- Landsat-5 TM (30 m spatial resolution): 02nd April 2001
- Landsat-7 ETM+ (30 m spatial resolution): 21st March 2011
- Landsat-8 OLI (30 m spatial resolution): 16th March 2021

These raw data or separate bands have been stored in a specific folder and by using ESRI ArcGIS 10.7.1 software (with ArcToolbox => Data Management Tools => Raster => Raster Processing => Composite Bands) these satellite imageries were geo-processed including the removal of haze and noise. The projection system - Universal Transverse Mercator (UTM) zone no. 43, and datum - World Geodetic System 1984 (WGS-84) were used for better calculation and verification of distances between utilities, riverbank, and land use land cover classes. The nearest neighborhood method was used for the transformation of

the raw satellite data to geo-referenced satellite data. An automatically generated root mean square error (RMSE) has been maintained at less than 0.23 (Figure 2). Digital image processing (DIP) and visual image interpretation techniques using ArcGIS 10.7.1 software were used for land use and land cover (LULC) mapping of the study area.

LULC Mapping and Change Pattern Analysis

The LULC pattern of any region is an outcome of various physio-cultural factors and their utilization by man in time and space. Image Classification Toolbar (ArcToolbox => Spatial Analyst Tools => Multivariate => Iso Cluster Classification) in ArcGIS 10.7.1 software has used to generate different raster based LULC layers of year 1991, 2001, 2011 and 2021. It is an essential tool for extracting quantitative information from remotely sensed image data. LULC of the study area comprises mostly of forest land (average 63%) and agricultural land (average 17%) (Figure 2). This initial observation is confirmed by the statistics given in Table 1.

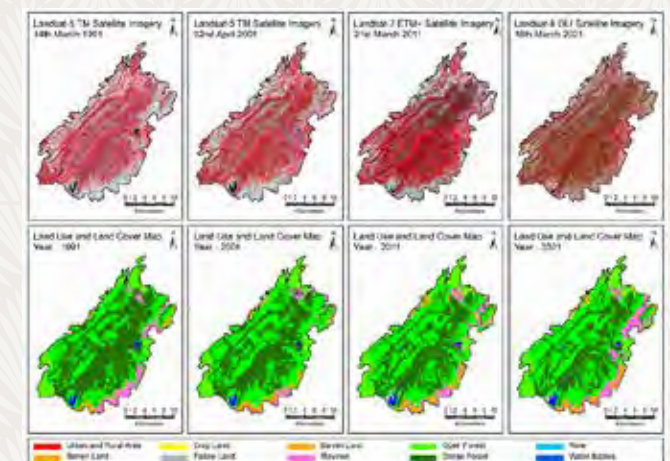


Figure 2. Satellite Imageries and LULC Maps of the Study Area

The post-classification approach is used in the study to detect the changes between two dates. In this approach images belonging to different dates are classified and labeled individually. Later, the classification results are compared directly, and the area of changes is extracted (Jensen, 1996; Yuan et al., 1999). Individual classification of two date images minimizes the problem of normalizing for atmospheric and sensor differences between two dates. To find out the change categories, the Image Analyst extension of ArcGIS 10.7.1 software was used. Images of two years were input and as a result, the output image contained the change categories. The summary of the LULC change pattern analysis of the Ranthambhore tiger reserve is given in Table 1.

Table 1. Land Use and Land Cover (LULC) Classes and Change Pattern Analysis

S. No.	LULC Classes	LULC Area (Km2)				LULC Change (Km2)		
		1991	2001	2011	2021	1991-2001	2001-2011	2011-2021
1	Settlement	2.31	2.57	4.47	7.86	0.26	1.90	3.39
2	Crop Land	40.54	53.27	85.31	40.44	12.73	32.04	-44.87
3	Fallow Land	89.94	90.52	60.49	78.62	0.58	-30.03	18.13
4	Barren Land	44.03	45.57	71.58	141.51	1.54	26.01	69.93
5	Open Forest	247.94	268.50	271.84	242.83	20.56	3.34	-29.01
6	Dense Forest	281.54	241.53	190.80	163.65	-40.01	-50.73	-27.15
7	Ravines	50.20	56.26	73.69	84.77	6.06	17.43	11.08
8	Riverbed	14.05	15.96	12.30	9.58	1.91	-3.66	-2.72
9	River	6.82	4.17	7.61	8.22	-2.65	3.44	0.61
10	Water Bodies	4.86	3.88	4.14	4.75	-0.98	0.26	0.61
	Total	782.23	782.23	782.23	782.23			

Overview of Forest Carbon Stock Measurements

The main carbon pools in tropical forest ecosystems are the living biomass of trees and understory vegetation and the dead mass of litter, woody debris, and soil organic matter. The carbon stored in the aboveground living biomass of trees is typically the largest pool. Estimating aboveground forest biomass carbon is the most critical step in quantifying carbon stocks and fluxes from tropical forests. Measurement protocols for other carbon pools are described elsewhere (Post et al., 1999; Brown et al., 2003; Pareta et al., 2011).

The dry biomass can be converted to carbon content by taking half of the biomass weight (carbon content ~ 50% of biomass; Westlake, 1966). Carbon is lost to the atmosphere as CO₂. To convert carbon in biomass to CO₂, the tonnes of carbon are multiplied by the ratio of the molecular weight of carbon dioxide to the atomic weight of carbon (44/12). Estimating the biomass density of forest components is, therefore, the first step in forest carbon accounting.

The InVEST 3.9.0 Carbon Model

Carbon storage on a land parcel largely depends on the sizes of four carbon pools: aboveground (AGB) biomass, belowground (BGB) biomass, soil organic (SOM), and dead

organic matter (DOM). The InVEST Carbon Storage and Sequestration model aggregates the amount of carbon stored in these pools according to the LULC maps. For each LULC type, the model requires an estimate of the amount of carbon in at least one of the four fundamental pools, described in Table 2.

Table 2. Carbon Stored in Above and Below-Ground Biomass Differs Strongly among LULC Classes

LULC Classes	Amount of Carbon Stored (Mg ha ⁻¹)*			
	AGB	BGB	SOM	DOM
Dense Forest	140	70	35	12
Sparse Forest	65	40	25	6
Crop Land	23	35	30	5
Fallow Land	15	35	30	4

LULC Classes	Amount of Carbon Stored (Mg ha ⁻¹)*			
	AGB	BGB	SOM	DOM
Scrub Land	30	30	30	13
Open Land	5	5	15	2
Urban Area	4	5	15	1
Other Land	0	0	0	0

*Note: The unit for all carbon pools is Mg of elemental carbon ha⁻¹. This means that if your data source has information on Mg of CO₂ stored ha⁻¹, you need to convert those numbers to elemental carbon by multiplying Mg of CO₂ stored ha⁻¹ by 0.2727.

The model runs on a gridded map of cells called raster format in ArcGIS software. Each cell in the raster is assigned a LULC type such as forest, pasture, or agricultural land, etc. After running the model in raster format, results have been summarized and given in Table 3.

Table 3. Year-wise Carbon Stored in Ranthambhore Tiger Reserve

Year	1991	2001	Change 1991-2001	2011	Change 2001-2011	2021	Change 2011-2021
Forest Area (Km2)	529.48	510.03	-19.45	462.64	-47.39	406.48	-56.16
Carbon Stored (Million Kg / Ha.)	32.35	30.66	-01.69	27.52	-03.14	24.36	-03.16

Over the past century, human activities like the burning of fossil fuels, deforestation, and urbanization have resulted in the high concentration of CO₂ and other greenhouse gases in the atmosphere. CO₂ is one of the most common greenhouse gases resulting in global warming which in turn brings about a rise in sea level, drought, deforestation, etc. The forest area in the Ranthambhore tiger reserve has continuously decreased from 1991 to 2021. In the last three

decades, the forest area (including open forest and dense forest) has lost 123.01 Km², subsequently, carbon storage and sequestration have also decreased from 32.35 (Million Kg / Ha) in 1991 to 24.36 (Million Kg / Ha) in 2021. Carbon storage and sequestration are decreased 7.99 Million Kg / Ha in the last three decades. Changes in forest area have resulted from human activities at large scale (tourism), and deforestation in the Ranthambhore tiger reserve.

Conclusion

Analysis of the carbon sequestration potential of the Ranthambhore tiger reserve can have great implications in assessing its input on mitigating climate change. Monitoring changes and time series analysis is quite difficult with the traditional method of surveying. Remote sensing and GIS analytical techniques can be applied for forest cover change detection and change in biomass. Through multi-temporal satellite images, it is not only possible to monitor the changes

in coverage over the years but also provide estimates of carbon stocks built-up or lost. Remote sensing provides the synoptic view of the study area with coverage on different timelines used for detection of change. Remotely sensed satellite data is a technology to calculate the biomass and ultimately carbon sequestration value of plants in a larger area in quick turnaround time and is cost-effective.

