

Decadal Trends in Forest and Agricultural Land Dynamics: A Remote Sensing-Based Study of Valmiki Tiger Reserve of Bihar, India and its Eco-Sensitive Zone

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ABSTRACT

The present study analyzes four decades (1975–2015) of land use and land cover (LULC) changes in the Valmiki Tiger Reserve (VTR) and its surrounding eco-sensitive zone, located within the Terai Arc Landscape of India. Using multi-temporal remote sensing data and GIS techniques, the study reveals dynamic shifts in forest cover, agricultural expansion, shrubland growth, wetland resurgence, and barren land reduction. While forest cover exhibited a marginal increase due to early conservation efforts, the last decade (2005–2015) witnessed a negative growth trend, indicating rising anthropogenic pressure. Agricultural land expanded steadily, driven by population growth and land reclamation, while barren land showed a sharp decline as it was converted into

cultivable and shrub-covered areas. Wetlands and water bodies demonstrated positive growth in the final decade, reflecting either ecological restoration or improved classification. These findings underscore the importance of continuous LULC monitoring to guide conservation planning, especially in protected areas where human-wildlife conflict and habitat fragmentation remain pressing concerns. The study emphasizes the need for integrated land management strategies to ensure sustainable coexistence between biodiversity conservation and human development.

Keywords Land use land cover change, Remote sensing, Forest degradation, Valmiki Tiger Reserve, Terai Arc Landscape.

INTRODUCTION

The intensifying anthropogenic pressure on forests and natural ecosystems has emerged as a critical driver of biodiversity loss, contributing to the extinction of numerous wildlife species globally. Human-wildlife conflicts have become increasingly frequent and severe, driven by competition for space and resources. This escalating struggle has led researchers to describe the current biodiversity crisis as the “sixth mass extinction” of species (Dennehy *et al.* 2021).

Expanding human settlements, agricultural encroachments, and the construction of roads and railway networks in and around protected areas

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pose significant threats to wildlife and their habitats. Local communities residing near these conservation zones are highly dependent on forest resources such as firewood, fodder, and medicinal plants for their livelihoods. This dependence often leads to forest encroachment, habitat fragmentation, uncontrolled clearings, and even forest fires, exacerbating the degradation of these sensitive ecological regions.

The Himalayan region, in particular, has witnessed rapid vegetation loss in recent decades due to increasing population pressure and infrastructure development, including road and dam construction (Byers *et al.* 2024). The removal of vegetative cover has severely destabilized the fragile Himalayan ecosystem, making it more susceptible to soil erosion, landslides, rockfalls, and flash floods (Sharma *et al.* 2018). One of the most ecologically significant regions affected by these changes is the Terai Arc Landscape (TAL), a transboundary conservation area stretching from the Yamuna River in the west to the Bagmati River in the east (Anwar and Borah 2019). TAL encompasses diverse forest types, including sal forests, riverine woodlands, and grasslands (FSI 2015) that serve as critical habitats for large mammals such as tigers, rhinoceroses, elephants, leopards, nilgai, wild boars, and crocodiles (Anwar and Borah 2019). It is also home to several rare and endangered plant and animal species.

Despite its ecological importance, the TAL region has undergone extensive deforestation and habitat fragmentation, largely due to human-induced activities such as road building, dam construction, canal systems, and the expansion of settlements (Sharma *et al.* 2018). Many development projects have necessitated the displacement and subsequent resettlement of local communities, leading to population clustering around protected zones (Redmore *et al.* 2023).

In light of these challenges, it has become increasingly vital to monitor and analyze the spatiotemporal patterns of land use and land cover (LULC) changes in and around protected areas. A comprehensive understanding of these landscape dynamics is essential for designing effective conservation strategies and sustainable development programs. This study focus-

es on evaluating LULC changes within the Valmiki Tiger Reserve and its surrounding eco-sensitive zone over a 40-year period (1975–2015). By examining shifts in forest cover, agriculture, settlement expansion, and other land categories, the research aims to reveal the underlying trends and drivers of landscape transformation, thereby informing better ecological management and policy planning.

MATERIALS AND METHODS

Description of the area under study

VTR forms the eastern most part of the Himalayan Terai landscape in the Indian subcontinent and is known for its unique assemblage of bhabar and terai tracts. Bhabar track is characterized by boulders and pebbles deposited by rivers, while fine sediments deposits form the terai area of VTR (Champion and Seth 1968). The VTR is located in the north-western part of the West Champaran district of Bihar along the international border with Nepal. Geographically it is situated between 27° 10' N to 27° 30' N latitude and 83° 50' E to 84° 10' E (Fig. 1). VTR merges with Chitwan National park and Parsa Wildlife Reserve in Nepal. This trans-boundary wildlife track is geographically spread over 3000 sq km and it has been recognized as a Level 1 Tiger Conservation Unit by US-WWF. It is bounded by the India Nepal border in the north and the Uttar Pradesh-Bihar border in the west with a total geographical area of 901.70 sq km (Pattekar *et al.* 2021).

Gazette of India 2017 has declared a 0 meter to 9 km land area surrounding the Valmiki Wildlife Sanctuary, Valmiki National Park, and Valmiki Tiger Reserve in Bihar as Valmiki Wildlife Sanctuary, Valmiki National Park, and Valmiki Tiger Reserve eco-sensitive zone. The VTR eco-sensitive zone is spread over 323 villages covering an area of 835.76 sq. km. The eco-sensitive zone has been notified for conservation & protection of rich and unique biodiversity in VTR along with eliminating human-wildlife conflict.

Research methods and design

Various primary and secondary data sources have

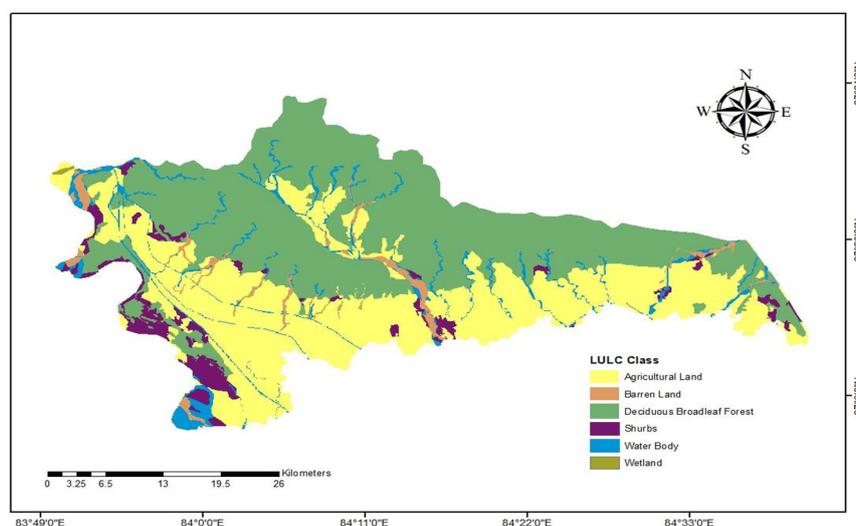


Fig. 1. Land use land cover classification-1975 (Source- Landsat MSS).

been used to prepare the land use land cover of the eco-sensitive zone and Valmiki Tiger Reserve. The primary source of data consists of field observations made during a field survey of the study area. The secondary data source includes interpretation of multi-time period satellite imageries (Landsat MSS, Landsat TM, and Landsat 8) and land use land cover map of 2005-06 at 50K scale and land use land cover map of 2015-16 at 50K study area assessed through thematic services in Bhuvan web portal. In addition to this several other data sources like- Google earth, the district map of West Champaran, Central ground water board report on the Status of Groundwater in West Champaran were used. Digital image interpretation of various period satellite imageries was performed in Arc-GIS 10.5 software and the outcome was validated through intensive ground truth techniques. Accuracy of the land use land cover map was enhanced by using the Normalized Deviation Vegetation Index (NDVI) which helps in demarcating the vegetative and non-vegetative areas. NDVI was estimated using two bands of satellite imagery – Red band (RED) and Near Infra-Red band (NIR) as follows-

$$\text{NDVI} = \frac{\text{NIR} - \text{RED}}{\text{NIR} + \text{RED}}$$

The range of NDVI values exists from +1.0 to -1.0. NDVI value for the non-vegetated area shows a value of 0.1 or less. NDVI value for sparse vegetation

ranges from 0.2 to 0.5 whereas; dense vegetation cover shows the value from 0.6 and 0.9. Analysis of vegetation cover through NDVI gives a rough measure of vegetation type and land surface condition (Johansen *et al.* 2015).

Land use land cover change analysis was performed using Arc GIS 10.5 software. Landsat satellite data of the study area for the past five decades was obtained from the USGS Earth Explorer web portal. To achieve maximum accuracy level radiometric and geometric correction of downloaded satellite data were performed in ERDAS 9.2 software. The study area shape file was used to subset the satellite imagery. Supervised land use land cover classification was performed in Arc GIS 10.5 software. Homogeneous sample pixels were used as training classes for land use classification. The Maximum Likelihood Classifier (MLC) technique was used for land use land cover classification (Dibs *et al.* 2020). Land use land cover map was prepared with six broad classes- Deciduous broad Leaves forest, agricultural land, barren land, shrubs, wetland, and water body. All canals, rivers, and lake areas have been categorized under water bodies. Barren land consists of rocky or sandy land without vegetation.

Accuracy assessment of classified land use map is an important step to know the correct level of result

(Yousefi *et al.* 2015). Accuracy assessment of the land use land cover map was performed by comparing the classified image with reference ground truth data collected during field survey and interpretation of the existing classified image (Kamrul *et al.* 2018). Reference ground truth data were collected by using a simple random sampling method with the help of GPS. Error report of the accuracy assessment was prepared by using reference data sets. To validate the accuracy of prepared land use land cover maps overall classification accuracy, Kappa statistics, user accuracy, and producer accuracy was used. The producers' and users' accuracy value for the supervised land use land cover analysis was around 92.7 percent (Elatawneh *et al.* 2014). The high value of Kappa statistics (0.94) and overall accuracy show a high accuracy level of classification performed. To determine the temporal dynamics of each land cover class, the decadal rate of change was calculated using the following formula:

$$\text{Rate of change (\%)} = \frac{A_t - A_{t-1}}{A_{t-1}} \times 100$$

Where,

A_t = Area of the land cover class in the current year (e.g., 1985, 1995),

A_{t-1} = Area of the land cover class in the previous time period (e.g., 1975, 1985),

The result is expressed as a percentage change per decade.

RESULTS AND DISCUSSION

The analysis of land use and land cover (LULC) changes over four decades (1975–2015) in the study

Table 1. Land use land cover class of VTR and its eco-sensitive zone for 1975 and 1985.

Land use land cover Class	1975	Percent	1985	Percent
Deciduous broadleaf forest	817.70	47.16	823.20	47.47
Shrubs	73.17	4.22	76.17	4.39
Water body	82.08	4.73	78.59	4.53
Agricultural land	719.93	41.52	735.58	42.42
Wetland	1.16	0.07	1.18	0.07
Barren land	40.08	2.31	19.40	1.12
Total	1734.12		1734.12	

Table 2. Land use land cover class of VTR and its eco-sensitive zone for 1995 and 2005.

Land use land cover Class	1995	Percent	2005	Percent
Deciduous broadleaf forest	824.62	47.56	826.25	47.65
Shrubs	78.82	4.55	75.40	4.35
Water body	73.72	4.25	72.27	4.17
Agricultural land	737.95	42.56	745.28	42.97
Wetland	1.18	0.07	1.18	0.07
Barren land	17.84	1.03	13.75	0.79
Total	1734.12		1734.12	

area reveals a dynamic transformation across key land categories. Forest cover exhibited a consistent, albeit modest, increase over the study period (Table 1). This positive trend can be largely attributed to the enforcement of stringent forest management policies and conservation efforts (Basu and Basu 2023). By 2015, forested areas accounted for approximately 48% of the total land cover, reflecting an increase from 817.70 sq km in 1975 to 821 sq. km in 2015 (Fig.1).

The stability and growth of forest cover were supported by restricted human access to protected forest lands (Yang *et al.* 2021). However, the most recent decade (2005–2015) registered a negative growth rate of -0.68%, likely driven by escalating anthropogenic pressures such as infrastructure development and habitat encroachment.

Dense forest cover is primarily concentrated within the designated boundaries of the Valmiki Tiger Reserve (VTR). High-density deciduous forests are observed across the Manguraha, Gobardhana, Raghia, Harnatand, Gonauli, and Chiutaha ranges,

Table 3. Land use land cover class of VTR and its eco-sensitive zone for 2015.

Land use land cover class	2015	Percent
Deciduous broadleaf forest	821	47.3
Shrubs	76.7	4.42
Water body	73.1	4.22
Agricultural land	750	43.20
Wetland	1.24	0.07
Barren land	13.1	0.76
Total	1734	

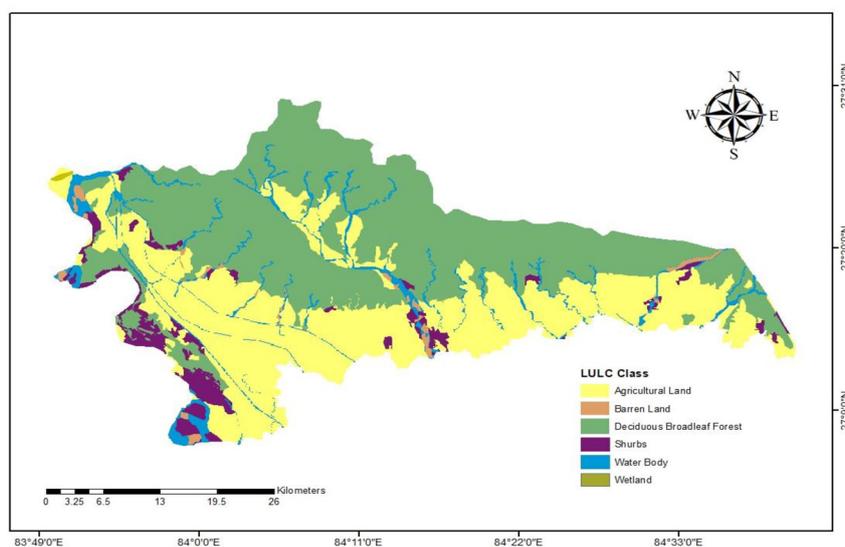


Fig. 2. Land use land cover classification-1985 (Source- Landsat TM).

as well as the adjoining Someshwar and Dun ranges. In contrast, the western zones of VTR—particularly the Valmikinagar and Madanpur ranges—exhibit lower canopy density and increased shrub cover. This region also supports a dense human population, with settlements such as Valmikinagar, Pipra, Laxmipur Rampurwa, Jharharwa, Dardari, Basantpur, Belahawa Madanpur, and Rampurwa located along its eastern boundary. The presence of multiple villages within the western VTR, coupled with road and railway

construction, has significantly disrupted wildlife corridors and weakened habitat conservation efforts. The Gandak River and its floodplain further define the physiographic character of this area.

The second dominant land use category is agricultural land, which constitutes roughly 42% of the study area (Table 2). Agriculture remains the primary livelihood activity, bolstered by fertile alluvial soil and sufficient water availability. Historically, large

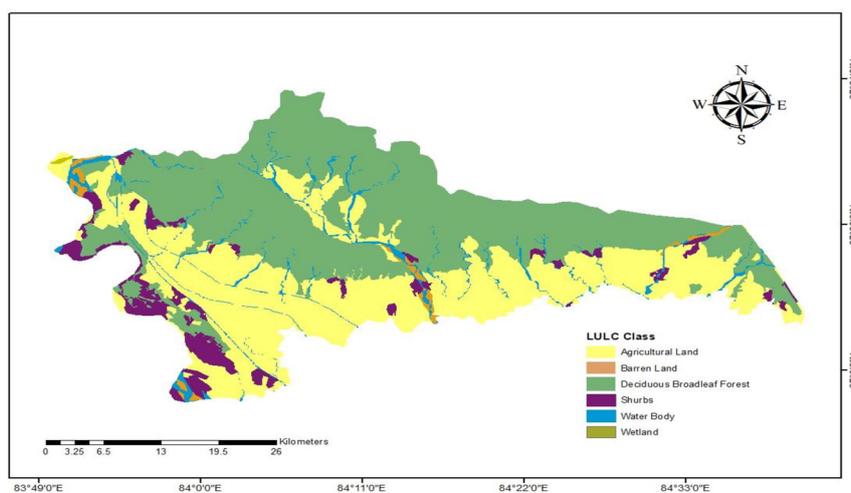


Fig. 3. Land use land cover classification-1995 (Source- Landsat TM).

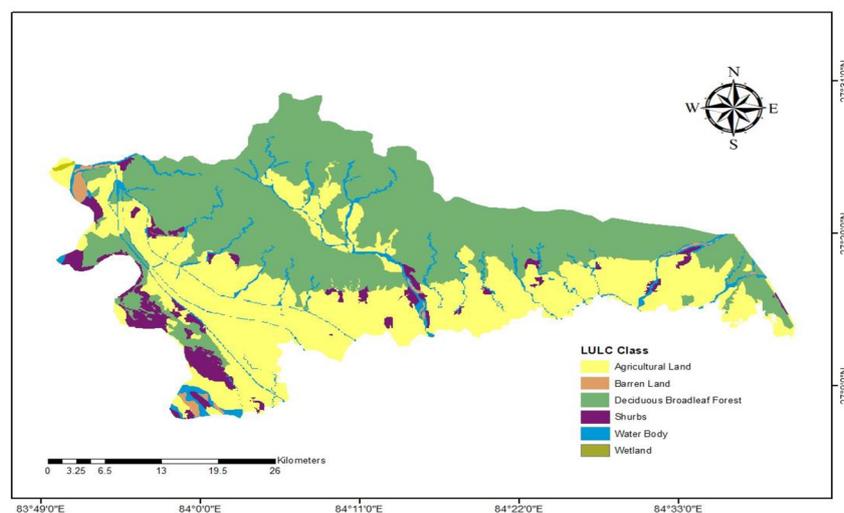


Fig. 4. Land use land cover classification-2005 (Source- Landsat TM).

tracts of forest were cleared—particularly by the Ex-Bettiah and Ex-Ramnagar estates—to facilitate timber extraction and agricultural expansion in the early 21st century. The area under agriculture expanded from 719.93 sq. km in 1975 to 735.58 sq km within a decade (Table 3). Approximately 16 sq. km of this increase originated from the reclamation of previously barren lands.

The trend of increasing agricultural land continued through 1995, 2005, and 2015 (Fig. 2), resulting in a cumulative gain of 29.64 sq km over four decades (Fig. 3). This transformation was primarily driven by population growth and land pressure, prompting the conversion of barren lands and shrub-covered areas into cultivable plots. Local practices such as draining water from ‘chaurs’ (seasonal wetlands) for crop cultivation also contributed to this change.

Shrubs form the third major land cover class, comprising approximately 4.5% of the total area (Fig. 4). Shrubland is predominantly concentrated in the western sections of the Valmikinagar and Madanpur ranges, where forest density is relatively low. These areas are under intense anthropogenic influence, resulting in forest degradation and the proliferation of shrub vegetation. Additionally, shrub patches are scattered across the western Gonauli range, the lower

stretches of the Little Gandak River, and the southern boundary of the Manguraha range. Shrublands often appear adjacent to forested zones and abandoned floodplains. Between 1975 and 1995, shrubland expanded at a growth rate of 4.10% (Table 4). However, a decline was noted in 2005, followed by resurgence between 2005 and 2015, when shrubland area increased by 4.42 sq km.

The barren land category experienced the most substantial transformation during the study period. The total barren land area dropped by 51.60% between 1975 (40.08 sq km) and 1985 (19.40 sq km). This declining trend persisted over subsequent decades: 1985–1995 (-8.04%), 1995–2005 (-22.93%), and 2005–2015 (-4.73%) (Table 4). The majority

Table 4. Rate of change in land use cover class of VTR and its eco-sensitive zone.

Land use land cover class	1975-85	1985-95	1995-05	2005-15
Deciduous broadleaf forest	0.67	0.17	0.20	-0.68
Shrubs	4.10	3.48	-4.34	1.70
Water body	-4.25	-6.20	-1.97	1.18
Agricultural land	2.17	0.32	0.99	0.58
Wetland	1.72	0.00	0.00	5.08
Barren land	-51.60	-8.04	-22.93	-4.73

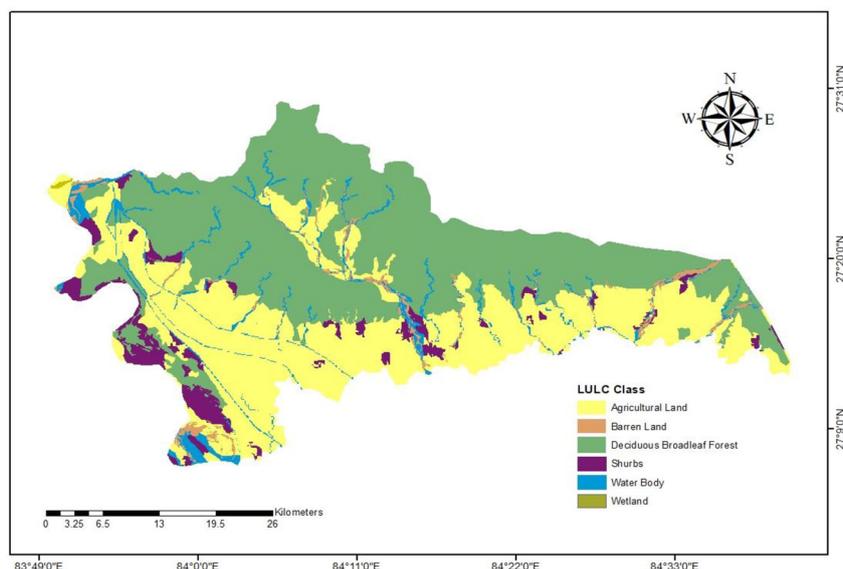


Fig. 5. Land use land cover classification-2015 (Source- Landsat 8).

of barren land was repurposed into agricultural or shrubland areas, a transition propelled by increasing land demand associated with population growth and land development pressures.

Wetland areas remained stagnant for two decades (1985–2005), following a modest increase in the early period (Fig. 5). However, a substantial spike of +5.08% occurred between 2005 and 2015, possibly due to increased monsoonal water retention, floodplain expansion, or the reclassification of seasonal wetlands as a distinct category. This marks a significant hydrological and ecological development in the region during the final decade.

CONCLUSION

The land use land cover change analysis of the study area exhibited rising human pressure and expanding agricultural land. The area under forest cover has remained almost unchanged, with a minor increase in growth rate from 1975 to 2005. Dense forest cover is limited within the VTR boundary. Forest cover along the Someshwar and Dun hills are dense and relatively undisturbed whereas, the western part of VTR (Madanpur and Valmikinagar range) has moderate dense patches of forests spread along the eastern part of Gandak River. The western part of

VTR has fragmented forest cover due to high human activities. Some part of eastern most VTR has also shown a decrease in forest cover due to expanding human activities. The shrub cover has expanded from 1975 to 1995. Madanpur and Valmikinagar ranges have substantial shrub cover around the dense forest patches. Another major shrub cover is found in the central part of the study area along the Little Gandak course. A significant change in barren land cover has been noticed during the study period. The total area under barren land has decreased throughout the four decades and is being converted into agricultural land and shrubland.

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