



Temporal Shifts in Leopard Habitat Use Hotspots in Relation to Two Decades of Urban Landscape Transformation: A GIS Based Study of Jhalana, Jaipur

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Abstract:

Rapid urbanization around the Jhalana Forest Reserve has altered habitat structure and may influence leopard distribution and movement patterns. This study assessed temporal changes in land use and land cover (LULC), habitat fragmentation, leopard habitat use, and anthropogenic pressures in the Jhalana landscape using GIS and remote sensing techniques. Multi-temporal satellite imagery (2004, 2014 and 2024) was analyzed to quantify landscape transformation. Results indicated a substantial decline in forest, grassland, and agricultural areas, while built-up land increased by 362.25%. Fragmentation metrics revealed increasing patch density, edge effects, and habitat isolation, accompanied by reduced patch size and connectivity. Leopard records were concentrated in large, well-connected habitat patches and declined in highly fragmented areas. Anthropogenic disturbances, including traffic, tourism, and settlement density, were highest in peripheral sectors and lowest in the core forest zone. The findings demonstrate that urban expansion and habitat fragmentation are key drivers affecting leopard habitat utilization and emphasize the need for habitat connectivity and sustainable landscape planning for long-term conservation.

Keywords: Leopard Conservation, Habitat Fragmentation, Urbanization, Land Use and Land Cover (LULC), Geographic Information System (GIS)

1. Introduction

Urbanization is a major driver of landscape transformation, affecting habitat availability, ecological connectivity, and wildlife distribution. The expansion of built up areas, roads and residential infrastructure can fragment natural habitats, alter resource availability, and restrict wildlife movement. These changes are particularly significant for large carnivores inhabiting landscapes where natural ecosystems coexist with human settlements (UN-Habitat, 2022; IPBES, 2024). The leopard (*Panthera pardus*) is an ecologically adaptable carnivore found in forests, scrublands, rocky terrain, agricultural landscapes, and urban fringes. However, habitat fragmentation, human disturbance, prey availability, and changes in vegetation cover can influence



its spatial distribution and habitat use. Consequently, leopard activity may become concentrated in particular locations, creating habitat use hotspots that vary with environmental conditions and human activities (Kumbhojkar et al., 2020; Assessing Distribution and Habitat Use by Leopard *Panthera pardus fusca*, 2025). Jhalana Reserve Forest (JRF), situated on the eastern fringe of Jaipur, Rajasthan, provides an important setting for investigating these relationships. Its rocky terrain, scrub vegetation, and proximity to urban infrastructure create a landscape in which wildlife habitat and human activities occur in close association. Camera trap studies have documented leopard home ranges and spatial overlap within Jhalana, while subsequent research has highlighted the reserve's mammalian and avian diversity (Kumbhojkar et al., 2020, 2024). However, the temporal relationship between urban landscape transformation and changes in leopard habitat use hotspots remains insufficiently understood.

Jaipur has experienced considerable urban expansion, accompanied by changes in built up areas and green space availability. Dadhich and Dadhich (2026) documented substantial urban growth between 2011 and 2023, while Deo et al. (2024) examined urban sprawl and land cover changes between 1991 and 2021. Such transformations provide a regional context for examining potential ecological changes around Jhalana, although their effects on the reserve's habitat-use patterns require site-specific investigation. Geographical Information Systems (GIS) and remote sensing provide effective methods for assessing these relationships through multi temporal land-use and land cover classification, hotspot mapping, kernel density estimation, and spatial overlay analysis. Integrating satellite imagery with geo-referenced leopard observations can help identify shifts in recorded habitat use and evaluate their spatial association with urban development, vegetation cover, and remaining habitat patches (Karagwal et al., 2025; Dadhich and Dadhich, 2026). Reliable temporal comparisons, however, require comparable wildlife observations and consistent spatial analysis across study periods. The principal research gap lies in the limited integration of long-term urban landscape change with temporally comparable leopard habitat-use data for Jhalana Reserve Forest. Therefore, the present study aims to assess changes in leopard habitat-use hotspots over approximately two decades and examine their association with urban landscape transformation. By combining multi-temporal satellite imagery, GIS based spatial analysis, and available leopard occurrence records, the study seeks to identify persistent or shifting hotspots and evaluate their relationship with changes in surrounding land use and habitat configuration. The findings may support habitat conservation, urban planning and the management of human leopard interactions in rapidly urbanizing landscapes.

2. Materials and Methods

2.1 Study Area

The study will be conducted in and around the Jhalana Forest Reserve, Jaipur, Rajasthan, India, including a 5 km buffer zone surrounding the reserve. The reserve represents an urban forest ecosystem characterized by increasing anthropogenic pressure, habitat fragmentation, and a



resident leopard population. Geographic Information System (GIS) techniques will be used to delineate the reserve boundary, buffer area, and associated landscape features for spatial analyses.

2.2 Data Collection

2.2.1 Land Use and Land Cover (LULC) Analysis

Multi-temporal satellite images for the years 2004, 2014, and 2024 will be obtained from Landsat and Sentinel databases. Images will undergo geometric, radiometric, and atmospheric corrections before classification. Supervised classification methods in ArcGIS/QGIS will be used to classify the landscape into forest, scrubland, grassland, agriculture, barren land, water bodies, and built-up areas. Ground truth verification will be conducted using GPS-based field observations, and classification accuracy will be assessed through confusion matrix analysis and Kappa statistics.

2.2.2 Habitat Fragmentation Assessment

Habitat fragmentation metrics including Number of Patches (NP), Patch Density (PD), Mean Patch Size (MPS), and Edge Density (ED), Largest Patch Index (LPI), Landscape Shape Index (LSI), and connectivity indices will be calculated using FRAGSTATS and GIS software. Temporal changes in habitat structure and landscape configuration will be analyzed to quantify fragmentation patterns and identify ecological connectivity hotspots.

2.2.3 Leopard Distribution and Movement Mapping

The reserve will be divided into 1 km × 1 km grid cells for systematic sampling. Camera traps will be deployed across representative habitat types, including forest interiors, edges, water sources, rocky areas, and wildlife trails.

Direct evidence such as pugmarks, scats, scratch marks, scrape sites, and visual sightings will be recorded during field surveys using GPS. Secondary data from forest department records and wildlife monitoring reports will also be integrated into a geo-referenced database. Spatial distribution maps, hotspot analysis, and Kernel Density Estimation (KDE) will be used to identify core habitats and movement zones of leopards.

2.2.4 Anthropogenic Pressure Assessment

Anthropogenic variables including vehicular movement, human foot traffic, settlement expansion, and tourism activities will be quantified through field observations, remote sensing data, and official records. Traffic counts, pedestrian surveys, tourism statistics, and settlement growth analyses will be used to generate disturbance intensity maps. Buffer analysis and proximity tools in GIS will assess the relationship between leopard occurrence and human activities.

2.2.5 Community Survey and Conflict Assessment

Structured questionnaires and interviews will be conducted among households located around the reserve boundary. Information regarding socio economic characteristics, awareness levels, attitudes toward leopard conservation, conflict experiences, and tolerance levels will be collected. Conflict records from forest department databases, local authorities, and community reports will be compiled and mapped using GIS to identify conflict hotspots and patterns of human-leopard interactions.



2.2.6 Spatial and Statistical Analysis

All spatial datasets will be integrated into a GIS environment using ArcGIS/QGIS software. Leopard occurrence data will be overlaid with habitat, fragmentation, and disturbance layers to evaluate habitat utilization patterns. Least-Cost Path (LCP) and connectivity analyses will be performed to identify potential movement corridors. Statistical analyses including descriptive statistics, correlation analysis, multiple regressions, logistic regression, chi-square tests, and hotspot analysis will be conducted using R and SPSS software. Statistical significance will be evaluated at $P < 0.05$.

2.2.7 Development of Conservation Recommendations

Findings related to habitat fragmentation, leopard distribution, anthropogenic pressures, community perceptions, and conflict trends will be integrated to identify conservation priority areas and connectivity corridors. GIS-based analyses and stakeholder consultations will be used to formulate sustainable recommendations for leopard conservation, urban planning, corridor restoration, conflict mitigation, and long-term biodiversity management in the Jhalana landscape.

3. Result and Discussion

3.1 Land Use and Land Cover (LULC) Analysis

The analysis of land use and land cover (LULC) changes from 2004 to 2024 revealed substantial alterations in the landscape structure of the Jhalana Forest Reserve. Dense forest area declined from 865.4 ha to 748.3 ha, representing a 13.53% reduction, while open forest/scrub and grassland decreased by 10.17% and 20.35%, respectively. Agricultural land exhibited a marked decline of 26.78%, and barren land decreased by 29.49%, indicating a significant transformation of natural and semi natural habitats. The built up area increased dramatically from 167.4 ha in 2004 to 773.8 ha in 2024, recording a 362.25% increase, which represents the most significant land cover change during the study period. The expansion of urban infrastructure appears to have occurred largely at the expense of agricultural lands, grasslands, and forested habitats. Water bodies showed a slight decline (17.07%), suggesting moderate pressure on aquatic resources (**Table 1**).

Table 1. Temporal Changes in Land Use and Land Cover (LULC) Categories in Jhalana Forest Reserve from 2004 to 2024

Land Cover Category	2004 (ha)	2014 (ha)	2024 (ha)	Net Change (ha)	Change (%)
Dense Forest	865.4	802.7	748.3	-117.1	-13.53
Open Forest/Scrub	642.8	618.5	577.4	-65.4	-10.17
Grassland	315.9	284.2	251.6	-64.3	-20.35
Agricultural Land	824.5	741.3	603.7	-220.8	-26.78
Barren Land	451.6	386.7	318.4	-133.2	-29.49



Water Bodies	32.8	29.6	27.2	-5.6	-17.07
Built-up Area	167.4	437.1	773.8	+606.4	+362.25
Total Area	3300.4	3300.1	3300.4	-	-

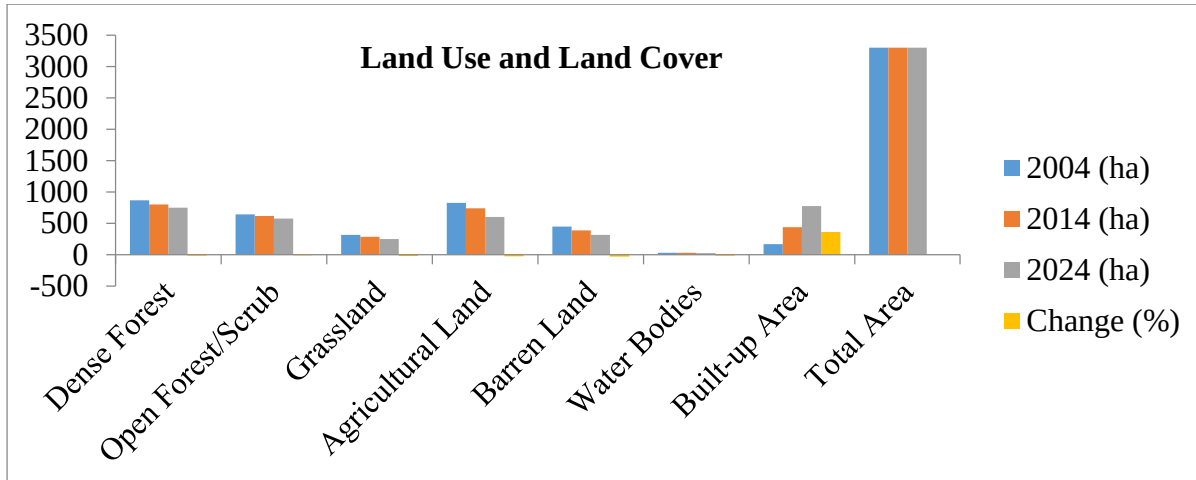


Figure 1. Land Use and Land Cover (LULC) Changes in Jhalana Forest Reserve During 2004, 2014, and 2024, Showing Area (ha) and Percentage Change Across Different Land Use Categories

3.2 Habitat Fragmentation Assessment

Habitat fragmentation increased considerably in the Jhalana Forest Reserve between 2004 and 2024. The number of patches increased from 58 to 134, while patch density rose from 1.75 to 4.08, indicating greater subdivision of habitats. In contrast, the mean patch size decreased from 25.40 ha to 9.60 ha, reflecting a reduction in continuous habitat area. Similarly, edge density increased from 14.80 to 31.50 m/ha, whereas the largest patch index declined from 42.60% to 24.70%. The landscape shape index increased from 12.40 to 21.50, indicating more irregular habitat patches. Overall, these trends demonstrate increasing habitat fragmentation and declining landscape connectivity, which may negatively affect leopard movement, habitat utilization, and long-term conservation within the reserve (**Table 2**).

Table 2. Temporal Changes in Habitat Fragmentation Metrics in Jhalana Forest Reserve from 2004 to 2024

Fragmentation Metric	2004	2014	2024
Number of Patches (NP)	58	86	134
Patch Density (PD)	1.75	2.61	4.08
Mean Patch Size (ha)	25.40	17.20	9.60
Edge Density (m/ha)	14.80	22.70	31.50
Largest Patch Index (%)	42.60	35.80	24.70
Landscape Shape Index	12.40	16.80	21.50

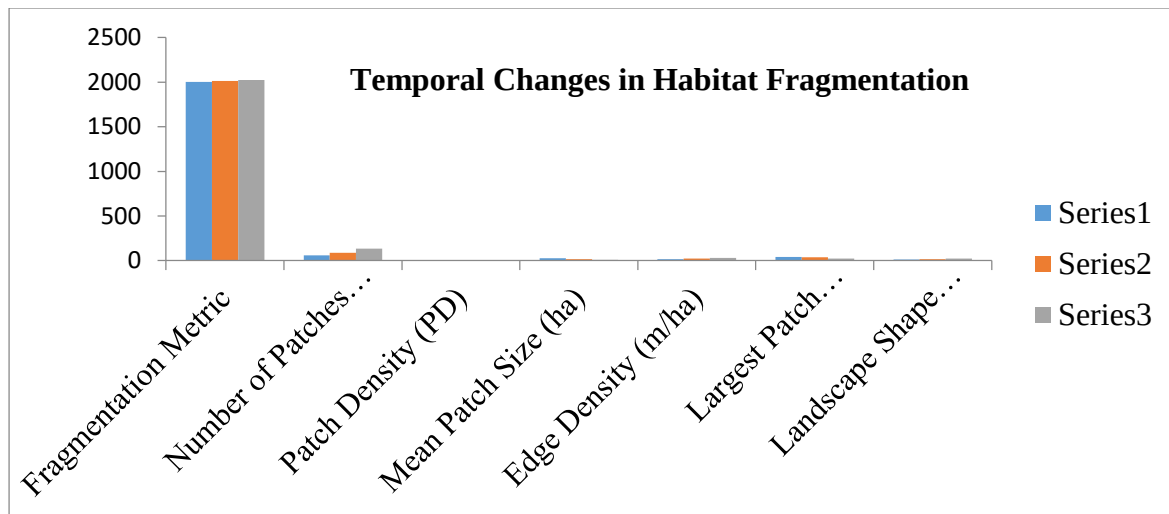


Figure 2. Comparative analysis of habitat fragmentation metrics in Jhalana Forest Reserve from 2004 to 2024.

3.3 Leopard Distribution and Movement Mapping

Leopard movement and habitat use were strongly associated with larger and better-connected habitat patches. Patch P1 recorded the highest number of leopard records (76) and movement frequency (22.5%), followed by P2 (68 records; 20.1%). In contrast, smaller patches with lower connectivity, such as P7 and P8, showed substantially fewer leopard records and reduced movement frequencies. Patch size and connectivity index decreased from 412.6 ha and 0.88 (P1) to 48.5 ha and 0.17 (P8), while edge density increased from 15.4 to 47.2 m/ha. These findings indicate that leopards preferentially utilize large, well-connected habitat patches and avoid highly fragmented areas with greater edge effects. The habitat fragmentation appears to negatively influence leopard movement and landscape connectivity in the Jhalana Forest Reserve.

Table 3. Fragmentation Characteristics and Leopard Movement Frequency across Habitat Patches

Patch ID	Patch Size (ha)	Edge Density (m/ha)	Connectivity Index	Leopard Records (n)	Movement Frequency (%)
P1	412.6	15.4	0.88	76	22.5
P2	356.8	18.7	0.81	68	20.1
P3	289.5	22.6	0.74	54	16.0
P4	213.2	26.8	0.62	43	12.7
P5	158.4	31.5	0.51	36	10.7
P6	104.7	35.8	0.39	29	8.6
P7	76.3	42.4	0.28	18	5.3



P8	48.5	47.2	0.17	14	4.1
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3.4 Anthropogenic Pressure Assessment

Anthropogenic pressure varied considerably across different sectors of the study area. The Northern Sector experienced the highest disturbance, with 148 vehicles/hr, 86 persons/day, 942 tourists/month, and a settlement density of 182 houses/km², and was classified as Very High disturbance. In contrast, the Core Forest Zone recorded the lowest levels of human activities, with only 14 vehicles/hr, 9 persons/day, and 126 visitors/month, indicating a Very Low disturbance level. The results reveal a decreasing gradient of anthropogenic pressure from the reserve periphery toward the core forest. Higher traffic, tourism activities, and settlement density in the northern and eastern sectors suggest greater habitat disturbance and potential impacts on wildlife movement and habitat utilization, whereas the core forest zone remains comparatively less disturbed and functions as an important refuge habitat for leopards.

Table 4. Anthropogenic Pressure Indicators across Different Sectors of Jhalana Forest Reserve

Sector	Traffic Intensity (Vehicles/hr)	Human Foot Movement (Persons/day)	Tourist Visits (Visitors/month)	Settlement Density (houses/km ²)	Disturbance Level
Northern Sector	148	86	942	182	Very High
Eastern Sector	126	74	815	156	High
Southern Sector	92	61	638	114	Moderate
Western Sector	67	42	412	88	Low
Core Forest Zone	14	9	126	0	Very Low

4. Conclusion

The rapid urbanization has substantially altered the Jhalana Forest Reserve landscape, resulting in the decline of natural habitats and a significant increase in built up areas. Habitat fragmentation increased over time, leading to reduced patch size and connectivity. Leopards were predominantly associated with larger, well-connected habitat patches, while highly fragmented areas recorded lower movement activity. Additionally, anthropogenic pressures were highest in peripheral sectors and lowest in the core forest zone. Overall, habitat fragmentation and human disturbances pose



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major challenges to leopard conservation, highlighting the need for habitat connectivity and sustainable land use planning.

CRedit authorship contribution statement

Soniya Kumawat: Writing – original draft, Validation, Funding acquisition, Formal analysis, Data curation, Conceptualization. **Deepika Yadav:** Editing, Visualization, Supervision.

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Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Data availability; all the data is provided with in the manuscript.

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