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# Spatio-Temporal Changes in Forest Cover and Forest Fragmentation in the Northern Western Ghats

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**ABSTRACT**
The Western Ghats of India is rich in variety of flora and fauna and specially known for its endemism. The growing urbanization, expansion of agriculture and other anthropogenic interferences results in forest fragmentation and degradation of habitat. Spatio-temporal changes in forest cover and the variation in forest fragmentation in the Anjaneri, Panchgani, and Kas Plateau regions of the Western Ghats for the years between 1989 and 2015 were assessed. Thematic maps of the area were generated using multitemporal satellite images and geospatial techniques for the years of 1989, 1999, 2006, and 2015. Substantial decline in area under forest cover of the study area occurred during this period. Deforestation at Panchagani in comparison is higher than that at Aanjaneri and Kas. The causes of decline in area under forest are increasing area under agriculture, expansion of plantation agriculture, increasing built-up area and tourism infrastructure development. The forest fragmentation analysis revealed increase in the number of forest patches and decrease in patch size over the period. Rapid landscape transformation at the outer edges of the forest regions effects more habitat fragmentation and loss within the core forest area. The Anjaneri, Panchgani and Kas Plateau regions are ecologically and culturally significant. There is an urgent need of forest conservation measures and sustainable land-use planning which includes control of deforestation, promoting reforestation efforts, and improving landscape connectivity by establishing ecological corridors. The study also recommends policies based on principle of judicious balance in development activities with consideration preservation and restoration of the natural environment to preserving the environmental stability of this biodiversity hotspot region.

**Key words**: Forest fragmentation, Spatio-temporal analysis, Geospatial techniques, Ecological corridors, Biodiversity conservation, Western Ghats

## INTRODUCTION

Globally, it has been recognized that habitat loss and fragmentation are major problems for the preservation of biological diversity. The environment has been altered by human activity to the extent that most of the landscape patterns show a mosaic of populated areas, agricultural land, and scatted fragments of natural ecosystems (Midha and Mathur 2010). The dynamic process of fragmentation causes noticeable shifts in the pattern of habitat in a landscape over a period of time. Simultaneous decrease of forested area, expansion of forested edge, and separation of large forested regions into smaller, non-contiguous fragments is defined as fragmentation of forested landscape (Laurance 2000, Collingham and Huntley 2000, Fahrig 2003). Western Ghats is a global biodiversity hotspot, due to its distinct habitats and rich diversity of species. It also has significant ecological relevance for carbon sequestration, water supply, and habitat for a wide variety of flora and fauna. However, growing human activities like urbanization, agriculture, and infrastructure development have led to significant changes in the land cover and the fragmentation of the surrounding forests (Lele and Joshi 2009, Biswas and Khan 2011, Leal et al. 2012, Fischer and Lindenmayer 2007, Geist and Lambin 2002), and loss of biodiversity. For successful conservation and management of this ecologically vulnerable area, it is essential to comprehend the spatio-temporal patterns of changing forest cover and forest fragmentation.

Historical distribution and cover of the forests in India is not widely assessed and literature has only quantified a small portion of the deforested and degraded areas (Giriraj et al. 2008, Chakraborty 2009, Panigrahy et al. 2010). However, most of these

studies have not specifically addressed the impact of land use change on fragmentation of the landscape. As a result, it could be a highly relevant descriptor when assessing change over time, fragmentation, or the spatial connection between habitats. Satellite imaging is being used to analyze to assess spatial and temporal habitat fragmentation (McGarigal 2002, Parent et al. 2007). Programmes that provide a visual output either in vector or raster modes is used to assess forest fragmentation. Increased resource exploitation and changes in the geographic distribution of land cover are the results of growing human and livestock population. Large, continuous forests become fragmented when they are divided into smaller blocks due to road construction, farming, urbanization, or other types of altered landscapes which require landscape assessments to understand the changing biodiversity status (Roy and Tomar 2000, Reddy et al. 2013).

Few recent studies have addressed the impact of various anthropogenic activities which caused forest fragmentation through different approaches (Jaybhaye et al. 2022, Riitters et al. 2016, Sahana et al. 2015, Rose et al. 2015). These studies have revealed that core forests have become more isolated and fragmented. The aim of this study is to analyze spatio-temporal change in forest cover, nature of forest fragmentation and examine factors causing degradation of forest.

## STUDY AREA

The study areas are part of Western Ghats that includes the Anjaneri hill, Panchgani hill, and Kas Plateau (Fig. 1). These areas are known for their ecological significance, the extent of their forest cover, and availability to historical ancillary data (Jaybhaye et al. 2021). These places are primarily popular tourist destinations in the state of Maharashtra that are known for unique biodiversity preserved through time. Anjaneri hill is famous for unique flora, seasonal flowering, trekking and well-known pilgrim site of Lord Hanuman's birth place. The Kas Plateau is famous for its scenic beauty, unique environment, and mainly wide range of floral plant species. Panchgani is a well-known hill station and recognized as a tourist destination. Each location is significant in its own way, and the forest is rich in flora and fauna. The locations of study are between 1100-to-1300-meter amsl.

## MATERIALS AND METHODS

### Data Collection and image classification:

Using a landscape fragmentation tool created by the Centre for Land Use Education and Research (CLEAR) at the University of Connecticut (Riitters et al. 2004, Parent et al. 2007), the degree of fragmentation in the Anjaneri, Panchgani, and Kas Plateau has been assessed. For the purpose of the analysis to give visual outcomes, a geospatial technique is used (MacLean and Congalton 2010). The maps of land use and land cover (LULC) for the study were generated using USGS Earth Explorer Landsat satellite imagery for the years 1989, 1999, 2006, and 2015. In order to classify the land cover classes, data from the Landsat 5 TM, Landsat 7 ETM+, and Landsat 8 OLI scenes of the cloud-free dry season were used (Batar et al. 2017) (Table 1). The selected RS data are based on their availability, dataset quality and the spatio-temporal importance of the area.

LULC classification was done using hybrid image classification approaches such supervised, unsupervised, and visual classification in the Erdas imagine 2014. In order to rectify and validate the LULC results, an extensive fieldwork was done (Jaybhaye et al. 2022). The classification of satellite images as open vegetation, dense vegetation, settlements, agricultural, fallow land, barren land, shrubland, and water bodies was successfully completed.

### Forest Fragmentation tool

The Landscape Fragmentation Tool2 (LFT) developed by CLEAR researchers to identify internal and external fragmentation categories for a certain land cover feature. The LFT was used in order to assess the level of forest fragmentation in the Western Ghats (Holdt et al. 2004, Vogt et al. 2007, Parent et al. 2007, Hurd and Civco 2010). This model was created by Vogt et al. (2007) to develop a method for categorizing fragmentation types based on image morphology. According to the expert opinion, an edge width of 100 m was suitable for assessment. Using ArcGIS's spatial analyzer tool, reclassified

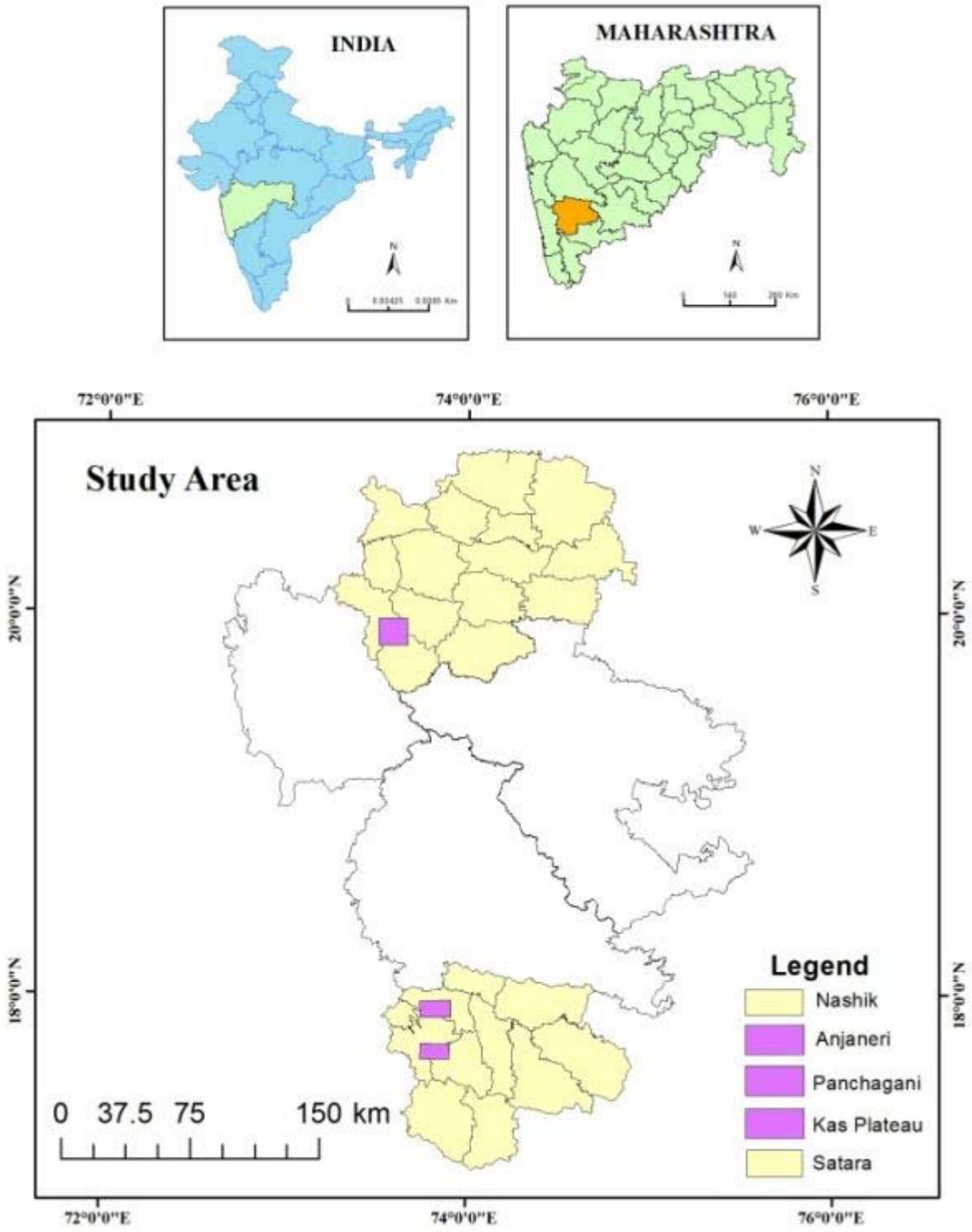


Figure 1. Study area map

LULC was divided into non-forest and forest classes, and only the forest class was utilized for the LFT fragmentation analysis.

The non-forest classes such as agriculture, barren land, fallow land, settlement, scrubland, and water bodies excluded in the analysis and core forest, edge forest, patch forest, and perforated forest are the four main forms of forest fragmentation that are categorized and quantified from the dense and open vegetation classes of the forest category. The assessment was based on four main categories such as patch, edge, perforated, and core forest and

Table 1. The remote sensing data source

| Acquisition Date | Satellite | Sensor | Source | Spatial resolution |
|---|---|---|---|---|
| 28-02-1989 | Landsat 5 | TM | USGS | 30 |
| 14-11-1999 | Landsat 7 | ETM+ | USGS | |
| 18$^{t}$-02-2006 | Landsat 7 | ETM+ | USGS | |
| 19-02-2015 | Landsat 8 | OLI | USGS | |

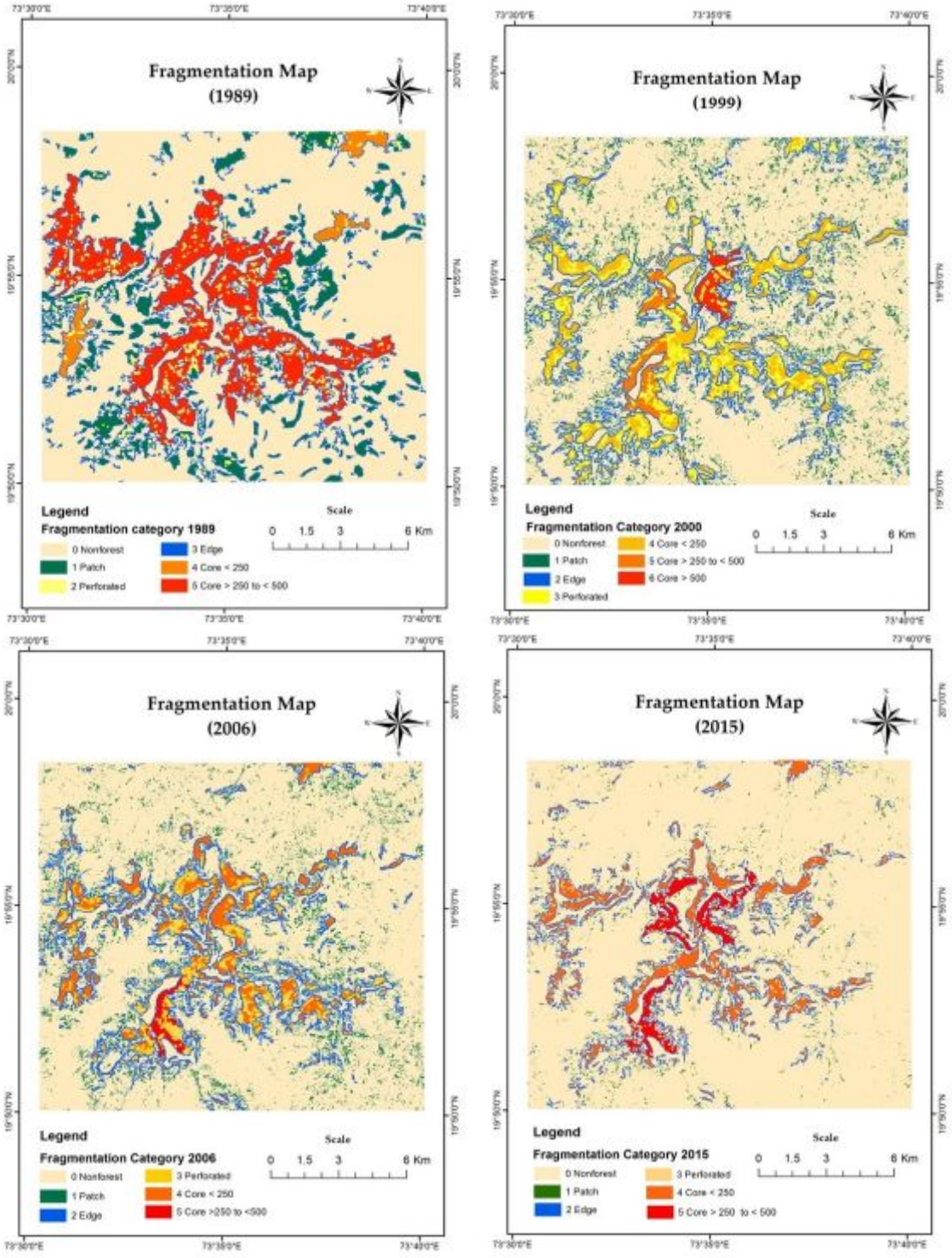


Figure 2. Fragmentation maps of Anjaneri (1989, 2000, 2006, and 2015)

Table 2. Forest area under various fragmentation categories at Anjaneri

| Class | 1989 | | 1999 | | 2006 | | 2015 | |
|---|---|---|---|---|---|---|---|---|
| | (ha) | (%) | (ha) | (%) | (ha) | (%) | (ha) | (%) |
| **Non-forest** | 16600 | 63.02 | 18420 | 69.93 | 19760 | 75.02 | 22230 | 84.40 |
| **Patch** | 650 | 2.47 | 1680 | 6.38 | 1630 | 6.19 | 420 | 1.59 |
| **Edge** | 2830 | 10.74 | 2770 | 10.52 | 2650 | 10.06 | 1650 | 6.26 |
| **Perforated** | 640 | 2.43 | 1160 | 4.40 | 940 | 3.57 | 220 | 0.84 |
| **Core < 250** | 1790 | 6.80 | 1710 | 6.49 | 1230 | 4.67 | 1310 | 4.97 |
| **Core 250 - 500** | 390 | 1.48 | 390 | 1.48 | 130 | 0.49 | 510 | 1.94 |
| **Core > 500** | 3440 | 13.06 | 210 | 0.80 | 0 | 0.00 | 0 | 0.00 |
| **Total** | **26340** | **100** | **26340** | **100** | **26340** | **100** | **26340** | **100** |

subdivision of core forest. The core forest subdivided into 3 different sizes: small core (250 acres or less), medium core (250–200 acres), and big core (>500 acres).

## RESULTS AND DISCUSSION

Forest fragmentation increased over the three decades in Anjaneri, Panchgani, and Kas Plateau area. Change under forest category of landscape was assessed for the periodic intervals between 1989 to 2015 at the three sites, which revealed that area under non-forest categories increased by 21% while 15% area under forest decreased at Anjaneri. The area of core forest categories (<250; 250-500 and >500) decreased gradually, except core > 500 which disappeared by 2006 itself (Fig. 2 and Table 2).

At Panchagani, the area under non-forest area increased by 29% while the core area reduced by 14% (Fig. 3 and Table 3). The perforated areas increased from 1989 and 1999, and then began to significantly decline in 2006. The fragmentation is quite high in 2015 as the core > 500 ha class decreased while the core <250 ha and core 250 to 500 ha classes increased.

At Kas Plateau the nanoforest area increased by 14% and the core area decreased by 18 %. The forest area, especially the core forest decreased drastically with time and reduced by 26.37% and Perforated area increased to 15.78% in 2015 (Fig. 4 and Table 4).

The area under forest cover in the western ghats has been decreasing and created serious concern for conserving endemic and other diverse species of the rich biodiversity (Jha et al. 2000). To check the forest degradation and comprehending rates of degradation with site specific information, the spatio-temporal analysis has relevance to design conservation plan. Western Ghats has site or relief specific diversity of phyto species. The forest cover on the plateau region has importance in context of unique plant species and ecotourism potential. Therefore, the forest cover on Anjaneri, Panchgani, and Kas Plateau has spatio-temporally analyzed for the period of three decades from 1989 to 2015. The analysis revealed that the forest area has been fragmenting over the period in various forest fragmentation categories i.e. patch, edge, perforated, and core forest. The forest fragmentation in form of various categories is significantly noted in the study region. The area under non forest categories has increased over the period on all the three selected plateau areas. The edge and core >250 categories are comparatively significant at Anjaneri and Panchgani Plateau. The edge, perforated and core >500 fragmentation categories are predominant at Kas Plateau. The studies, field observations and informal discussions with locals have reasoned the forest fragmentation scenario in the region. The causes for the forest fragmentation are population growth, agricultural intensification and expansion, forest encroachment mass tourism, infrastructural development, urban sprawl etc. (Jaybhaye et al. 2021). The proximity to major cities, increasing transportation network, poor land use planning and weak enforcement of environmental laws have been further accelerated the fragmentation in the study area. As a result of edge fragmentation increase in invasive species, and human-wildlife conflict (Badhe and Jaybhaye 2021) are reported.

Therefore, fragmented forests are becoming more vulnerable. The existence of unique and endangered species in the Western Ghats is threatened by the loss of continuous forest ecosystems. Strengthening sustainable landuse planning and legal check on illegal deforestation and formation of comprehensive policy are essential for efficient conservation and management of forest area. For the preservation of biodiversity and the restoration of ecological connections, protected areas may be created or expanded to restore degraded forest.

## CONCLUSIONS

The Anjaneri, Panchgani, and Kas Plateau are famous for its unique ecosystems and are surrounded by

Table 3. Forest area under various fragmentation categories at Panchgani

| Class | 1989 | | 1999 | | 2006 | | 2015 | |
|---|---|---|---|---|---|---|---|---|
| | (ha) | (%) | (ha) | (%) | (ha) | (%) | (ha) | (%) |
| **Non-forest** | 9980 | 58.91 | 7760 | 45.81 | 8720 | 51.48 | 12640 | 74.62 |
| **Patch** | 310 | 1.83 | 1000 | 5.90 | 1320 | 7.79 | 560 | 3.31 |
| **Edge** | 1150 | 6.79 | 1110 | 6.55 | 1400 | 8.26 | 1320 | 7.79 |
| **Perforated** | 1170 | 6.91 | 3160 | 18.65 | 980 | 5.79 | 440 | 2.60 |
| **Core < 250** | 460 | 2.72 | 360 | 2.13 | 320 | 1.89 | 1020 | 6.02 |
| **Core > 250 to < 500** | 130 | 0.77 | 120 | 0.71 | 110 | 0.65 | 620 | 3.66 |
| **Core > 500** | 3740 | 22.08 | 3430 | 20.25 | 4090 | 24.14 | 340 | 2.01 |
| **Total** | **16940** | **100** | **16940** | **100** | **16940** | **100** | **16940** | **100** |

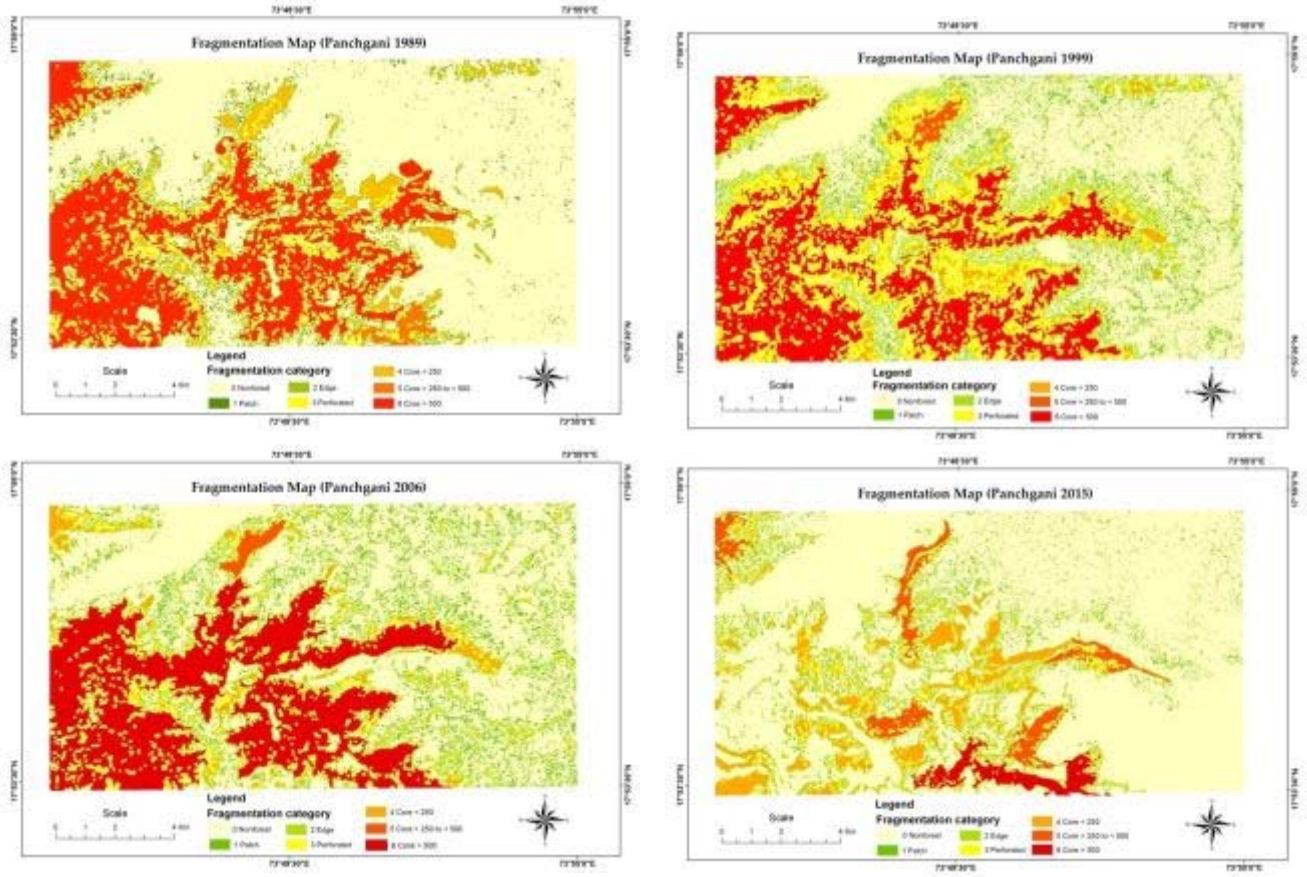


Figure 3. Fragmentation maps of Panchgani (1989, 1999, 2006, and 2015)

dense forest, however due to their famous tourist place tag and development of urbanization the area is becoming fragmented. This study mainly focussed on the three decade time scale from 1989 to 2015 in which most changes in the non-forest, core area, patches and perforated area were visible. In Kas area the perforate area increased over time period, but in Panchgani and Anjaneri it decreased. The Anjaneri, Panchgani, and Kas Plateau of the Western Ghats showed significant spatio-temporal changes in forest cover and increasing forest fragmentation. Over the duration of the study period, forest cover decreased and fragmentation increased, mainly as a result of human activities such as, agriculture, urbanization,

Table 4. Forest area under various fragmentation categories at Kas plateau

| Class | 1989 | | 1999 | | 2006 | | 2015 | |
|---|---|---|---|---|---|---|---|---|
| | (ha) | (%) | (ha) | (%) | (ha) | (%) | (ha) | (%) |
| **Non-forest** | 4040 | 26.90 | 6490 | 43.21 | 5800 | 38.62 | 6090 | 40.55 |
| **Patch** | 150 | 1.00 | 350 | 2.33 | 190 | 1.26 | 220 | 1.46 |
| **Edge** | 980 | 6.52 | 1480 | 9.85 | 1200 | 7.99 | 1130 | 7.52 |
| **Perforated** | 990 | 6.59 | 2330 | 15.51 | 1280 | 8.52 | 2370 | 15.78 |
| **Core < 250** | 150 | 1.00 | 540 | 3.60 | 360 | 2.40 | 310 | 2.06 |
| **Core > 250 to < 500** | 0 | 0.00 | 0 | 0.00 | 140 | 0.93 | 150 | 1.00 |
| **Core > 500** | 8710 | 57.99 | 3830 | 25.50 | 6050 | 40.28 | 4750 | 31.62 |
| **Total** | **15020** | **100** | **15020** | **100** | **15020** | **100** | **15020** | **100** |

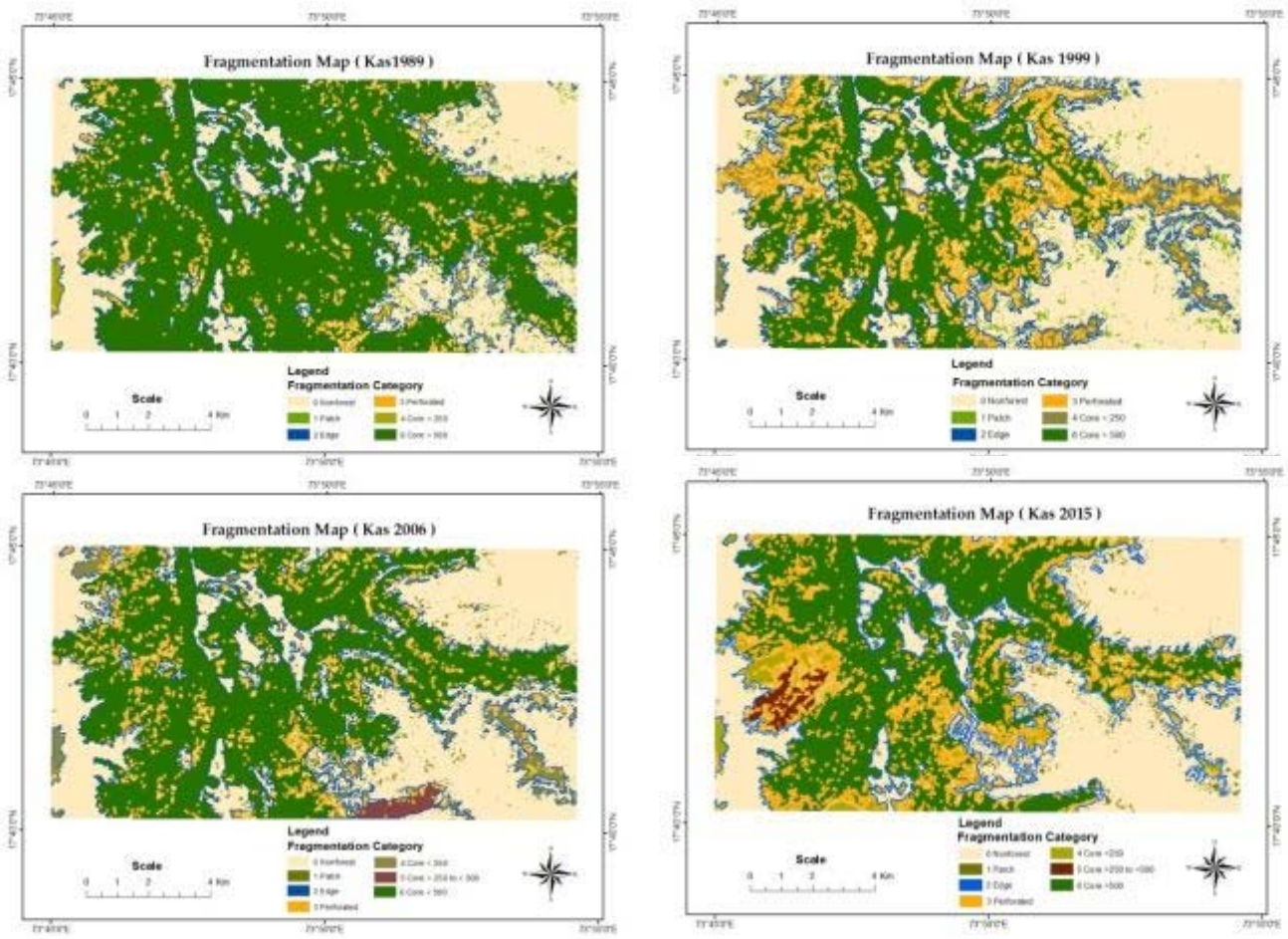


Figure 4. Fragmentation maps of Kas (1989, 1999, 2006, and 2015)

and infrastructure development. Non-forest area is increased more in Panchgani followed by Anjaneri and Kas. Panchgani have significant decrease in core area (41%) followed by Kas (18%) and Anjaneri by (15%). Non-forest area increased during this period in all three areas which is due to the unplanned tourism, urbanization development and other infrastructure necessities of the humans. As all three areas are ecological sensitive, it is essential to protect and conserve them. The present study highlights the alarming spatio-temporal changes in the forest cover and growing fragmentation in the Western Ghats (Anjaneri, Panchgani, and Kas Plateau). To preserve the remaining forested regions, immediate action is required to protect the unique biodiversity of this ecologically important region.

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