

Landscape fragmentation analysis using geospatial tools in Periyar Tiger Reserve, Kerala

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THESIS

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2023**

DECLARATION

I hereby declare that the thesis entitled “**Landscape fragmentation analysis using geospatial tools in Periyar Tiger Reserve, Kerala**” is a bonafide record of research done by me during the course of research and that this thesis has not previously formed the basis for the award of any degree, diploma, fellowship or other similar titles, of any other University or Society.



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INTRODUCTION



INTRODUCTION

The Himalayas, Western Ghats, Indo-Burma region, and Sundaland are four of India's biodiversity hotspots (Dash and Mao, 2022). The Western Ghats, also known as the Western Mountain range, is a chain of mountains that runs parallel to the western coast of the Indian peninsula and extends over an area of 160,000 km² (Gunawardene *et al.*, 2007). Its conservation is important both for the biodiversity as well as the ecological functions that are essential to safeguard the livelihoods of the several million people living in peninsular India. The Periyar Tiger Reserve (PTR) is one of the well-known protected areas (PA) saddled in the southern region of the Western Ghats, and is known for its luxuriant collection of different species of flora and fauna. Scenic beauty, religious and cultural heritage and the rich assemblage of flora and fauna along with the perennial river Periyar has become a perfect site for the nature lovers. The Periyar Wildlife Sanctuary with an extent of 777 km² area was brought under the Project Tiger in 1978 as the 10th Tiger Reserve in the country and named as Periyar Tiger Reserve. The core area of Periyar Wildlife Sanctuary, an area of 350 km² was declared as National Park in 1982. In 2007, an extent of 881 km² was notified as core or critical tiger habitat of PTR, which includes 733 km² of Periyar Wildlife Sanctuary and 148 km² of Reserved Forests of adjoining Goodrical Range of Ranni Division. An extent of 44 km² of Periyar Wildlife Sanctuary is notified as the buffer to the Tiger Reserve. Now PTR has a total area of 925 km² (Sukla, 2012). Even though the Periyar forest area is brought under conservational status, it is much important to know the change in the pattern of landscape fragmentation, if it had occurred.

Fragmentation has been identified as a key global issue for the conservation of forests (Reddy *et al.*, 2013). The process of forest fragmentation, a common phenomenon occurring in tropical forests, not only results into continuously forest getting fragmented but also brings about several physical and biological changes in the environment of forests (Jha *et al.*, 2005). Protected areas are considered as the landmark of conservation efforts, and the change in land use pattern can stimulate habitat loss and depletion or fragmentation outside protected areas. This will affect the entire ecosystem process within protected areas and its surroundings, which leads to loss of biodiversity (Hansen and Defries, 2007). Forests may be fragmented by a number of activities or events, either anthropogenic or natural in origin such as road construction, logging, conversion to agriculture, or wildfire (Wade *et al.*, 2003). Human activities have altered the environment to the degree that most common landscape designs portray mosaic of human settlements, agricultural land, and scattered parts of natural

ecosystems (Midha and Mathur, 2010). Disturbances in the form of fires and fragmentation still exist in our protected areas and may have significant conservation threat to flora and fauna (Athira *et al.*, 2017).

Temporal analysis using various spatial analytic softwares, shows that the loss of Indian forest area is 5.8 % (per cent) during 1975-2005. The annual rate of deforestation has been computed as 0.20% at national level (Reddy *et al.*, 2013). Based on the interpretation of ortho-rectified LISS III satellite data obtained from NRSC, the forest cover in the Kerala state is 21,253 km², which is 54.70% of the state's geographical area (FSI, 2021). But during 1975-1995, the protected areas in the state of Kerala had shown a huge increase in deforestation because of the plantation, agriculture, road, settlements, rehabilitation of people displaced by reservoirs, valley projects and other non-forestry purposes. From 2005, protected areas of Kerala were seems to be comparatively less reduced in terms of its area (Athira *et al.*, 2017). During 1975-2013, Idukki district showed a drastic reduction (18.83 %) in its forest cover and Periyar showed a drastic loss in core area (29.32 km²). During 1985-1995, Periyar tiger reserve had lost 24.19 km² forest areas (Athira *et al.*, 2017). Periyar Tiger Reserve sustains forest fragmentation, but information and documentation highlighting the impact of protected area in the case of fragmentation is limited. Also the studies explaining the upshot human interventions and natural calamities in promoting or deducting forest fragmentation is meagre.

Identifying human-caused forest fragmentation may be a useful tool for policy and decision making, allowing for improved risk assessments and better target oriented protection or remediation (Wade *et al.*, 2003). So the time demands a quick and accurate assessment of the changes happened and happening to the natural resources like forest. In addition to this, understanding the relationship between human behaviour and forest change or any other related land use change poses a major challenge for development projects, policy makers, and environmental organizations aiming at improving forest management of the world (Southworth and Tucker, 2001). Spatially explicit approach is indispensable to prioritise the ecosystems for biodiversity conservation (Athira *et al.*, 2017). The current trend in ecological studies dictates the integration of remotely sensed digital spectral data in to geographic information systems. Using remote sensing satellite imagery along with GIS tools has proven very useful for managing land resources for both researchers as well as environmental organizations (Lu *et al.*, 2004). Due to the availability of Landsat satellite data, remote sensing and GIS have gained importance in monitoring changes in land use as well as forest

fragmentation (Kumari and Asok, 2017). Geoinformatics approach is widely used to monitor land use change as well as forest fragmentation due to availability of Landsat satellite data. Remotely sensed imagery is the most successful tool for forest cover monitoring, as it offers a cost-effective option for frequent observations of vast areas (Carranza *et al.*, 2014). The FAO and others have turned to earth observation data, specifically Landsat imagery, to provide a more consistent depiction of global forest change (Hansen *et al.*, 2013). FRAGSTATS is a spatial pattern analysis program for quantifying the structure (*i.e.*, composition and configuration) of landscapes. The landscape subject to analysis is user-defined and can represent any spatial phenomenon. FRAGSTATS simply quantifies the spatial heterogeneity of the landscape as such and represented in either a categorical map (*i.e.*, landscape mosaic) or continuous surface (*i.e.*, landscape gradient, expected in version 4.4). It is incumbent upon the user to establish a sound basis for defining and scaling the landscape in terms of thematic content and resolution and spatial grain (Mcgarigal, 2015).

By using these technologies, the main objective of study was to evaluate forest fragmentation in and around Periyar Tiger Reserve boundary by analysing tri-temporal satellite derived data sets of the years 1987, 2000 and 2020 and also to analyse the land use land cover change in the study region of these years.

REVIEW OF LITERATURE



REVIEW OF LITERATURE

2.1 FUNDAMENTALS OF REMOTE SENSING AND GIS

Remote sensing technology started first with the photographs in early 19th century and developed to satellite imageries, is the art and science of gathering data (spectral, geographical, and temporal) about physical objects, regions, or phenomena without directly interacting with them. To better manage natural resources and safeguard the environment, remote sensing refers to the process of detecting the earth's surface from space by utilising electromagnetic wave qualities that are emitted, reflected, or diffracted by the sensed objects. Without physical contact, some method of information transmission via distance must be used. Definition given by United Nations states that, “Remote sensing means sensing of the earth’s surface from space by making use of the properties of electromagnetic wave emitted, reflected or diffracted by the sensed objects, for the purpose of improving natural resource management, land use and the protection of the environment” (Krishna *et al.*, 2018).

Based on radiation emitted or reflected from objects or areas in multitemporal and multiscale techniques, remote sensing gives crucial information about things at or near the earth's surface and the atmosphere. Satellite and/or airborne sensors are used in remote sensing to collect data about a particular object or area. Therefore, they depend on the characteristics of their physical, chemical, biological, and/or geological constituents. Electromagnetic radiation is measured and recorded by sensors mounted on a platform (particularly, satellite, aerial, or unmanned aircraft systems) above the surface of the earth. Light detection and ranging (LiDAR), radar, and high-resolution multispectral and hyper spectral imagers are a few examples of sensors that can be deployed from a few hundred metres to hundreds or even thousands of kilometres above the surface of the earth (e.g., orbital satellites) (Chamine *et al.*, 2021). The energy source capable of transmitting and propagating information is electromagnetic radiation (EMR), which is a component of the electromagnetic spectrum (EMS). The main focus of remote sensing is on how to use this energy. The EMS is divided in to regions on the basis of wavelengths ranging from 0.03 um (gamma ray) to 30 cm (radio wave). Other regions in EMS are: X-ray (0.03-3 um), Ultraviolet (0.03 to 0.4 μm), Photographic UV band (0.3 to 0.4 m), Visible (0.4 to 0.7 um), Infrared (0.7 to 100 pm), Reflected infrared band (0.7 to 3.0 um), Thermal infrared band (3 to 12 um), Microwave (0.1 to 30 cm) and Radar (0.1 to 30 cm) (Lillesand and Kiefer, 2000). Geographical information systems (GIS) are computer based tools for managing and storing

geographic data. Through a series of intensive, synergistic, technologically driven actions over the past years, GIS have become a fully functional support for resource management, similar to remote sensing. The advantages of earlier revolutions in computer technology and geography have been used to build developments. The potential contribution of GIS to sustainable forest management is immense and this is one of the best instruments for addressing problems with forest management (Franklin, 2001).

However, remote sensing technology has advanced significantly over the past three decades to include a variety of sensors that can operate at different image scales. Nearly 100 satellites have been launched into orbit over the past ten years to observe the land, oceans, and atmosphere as well as to advance our understanding of the mechanisms that are driving climatic change (Fu *et al.*, 2020). There are many different types of remote sensing data available for investigations involving natural resources. Earlier the most frequent data sources are Landsat Multi-Spectral Scanner (MSS), TM, SPOT, AVHRR, radar, and aerial photos. However at the moment, recently developed advanced sensors like the Moderate Resolution Imaging Spectroradiometer (MODIS) and the Advanced Space-Borne Thermal Emission and Reflection Radiometer (ASTER) are becoming more significant (Lu *et al.*, 2004).

2.2 FOREST AND LAND USE LAND COVER CHANGE

Forest and its resources are under the pressure of various disturbances which are caused by both the anthropogenic and natural reasons. The earth's forest cover has decreased from 62 million km² to 33 million km² over the past 8,000 years, roughly half of which has happened in the last three decades (Sunderlin *et al.*, 2005). In this scenario many of the world parties has put several steps forward to conserve forest ecosystem. The Sustainable Development Goals (SDGs), which were adopted by the United Nations in 2015 as a global call for action to end poverty, protect the environment, and ensure that by 2030 all people enjoy peace and prosperity, have made SDG goal 15 "life on land" which is to protect, restore, and promote sustainable use of terrestrial ecosystems, sustainably manage forests, combat desertification, and to stop and reverse land degradation and stop biodiversity loss (UN, 2023).

India is the 7th largest nation by encompassing a total area of 329 Mha (Ramamurthy, 2018). India is classified into biogeographic zones based on distinction in topography, land use, geography and climate. India has a total forest and tree cover of 80.9 million hectares, which is 24.62 per cent of its total land area. Overall area covered by trees and forests in the

country has increased by 2261 km² since the assessment of 2019. Out of this, a 1540 km² increase in forest cover and a 721 km² increase in tree cover have been recorded (FSI, 2021). According to the India state of forest report (2021), out of 38,852 km² of total geographic area of Kerala 11,522 km² was recorded as reserve forest, which is 29.66% of the total geographical area.

The term "land cover" refers to the biological and physical covering of land, including plants, water, bare soil, and/or man-made buildings (Ellis and Pontius, 2007). The influence of biotic and abiotic factors on the dominant land use and land cover of the area is reflected in spatial land use and land cover change. By looking at geographical patterns, rates of change, and trends in a temporal database, one may gain a geographic knowledge of land use change processes. Climate change and ecological sustainability are both seriously impacted by the current changes in land use and land cover (Roy and Roy, 2010). In order to provide a comprehensive picture of the spatial extent of land use and land cover at a specific moment, remote sensing is crucial. Changes in the land cover have an impact on land usage, and the reverse is also true. The deterioration of the land is not always implied by changes in land cover due to land use. However, a number of societal factors, including several changing land use patterns, lead to changes in the land cover that have an impact on biodiversity, water and radiation budgets, trace gas emissions, and other processes that interact to affect the climate and biosphere. For a better knowledge of landscape dynamics over a known length of time with sustainable management, land use and land cover change detection is crucial. Natural occurrences and anthropogenic activity are the major drivers of land use and land cover changes, which in turn lead to changes that might have an influence on natural ecosystems (Rawat and Kumar, 2015).

Several studies based on the land use land cover change where taken place all over the world helps the land managers and scientist community in understanding landscape dynamics (Rawat and Kumar, 2015, Mishra *et al.*, 2020). Along with that many such studies focus on relating the land use change with other factors *viz*, effects on surface temperature (Gogoi *et al.*, 2019), impact on water resources (Wagner *et al.*, 2013), influence in flooding (Zope *et al.*, 2016) and so on. According to Jha *et al.*, (2000), in the studied area of around 40,000 km² in the southern part of Western Ghats, a loss of 25.6% in forest cover were observed from 1973 to 1995. Here dense forest was reduced by 19.5% and open forest was decreased by 33.2%. Also increase in 26.64% of degraded forest was also recorded.

2.2.1 Conservancy of Tiger Reserves

Panthera tigris tigris, sometimes known as the "charismatic carnivore," is regarded as an umbrella species since it indirectly contributes to the protection of several other species at the ecosystem and landscape levels. The flagship initiative in India, Project Tiger, aims to protect this important species in its natural habitat. Landscapes that are continuous, undisturbed, and non-fragmented, are necessary for tigers to survive. For the in-situ conservation of tigers, the Wildlife Protection Act, 1972 (2006 amendment) allows for the designation of a region as a "Tiger Reserve." A tiger reserve is made up of a core area that is protected outright for the conservation of tigers and a buffer area, which is a multiple-use area prioritised for conservation over other land uses. This helps to maintain a balance between wildlife and human activities for the sake of local residents' rights to development, social advancement, and cultural preservation (ISFR, 2021). One of the most endangered species on the planet is the tiger. These gorgeous felines, which we are accustomed to seeing in captivity, are steadily losing their natural population. Given its significance, a unique chapter on "Forest Cover Assessment in Tiger Reserves and Tiger Corridor Areas of the Country and Decadal Change in Forest Cover" has been included to the India State of Forest Report (ISFR) for the year 2021 in addition to the usual chapters.

2.2.1.1 Periyar Tiger Reserve

The forests of Western Ghats are good representatives of non-equatorial tropical evergreen forests of the world. Even if it's covering only 5% of the total geographical area of the country, it contains more than 4000 species of plants which account for 27% of the total floral wealth of the country (Ramesh *et al.*, 1997). The landscapes of Western Ghats are very heterogeneous ranging from Arabian Sea coast to montane heights of above 2000 m and rainfall ranging from less than 1000 mm to 6000 mm (Chandran, 1997). The Periyar–Agasthyamalai landscape is ecologically important within the Western Ghats due to its watershed and biodiversity significance. The Periyar Tiger Reserve (PTR) and surrounding protected areas, covering areas in Tamil Nadu and Kerala, make up the largest tiger conservation landscape in the southernmost Western Ghats. Since 1934, there has been a lengthy history of conservation. Two Divisions—Periyar east and west, are in charge of administrating the Periyar Tiger Reserve (Gok, 2021). The reserve also offers a host of eco-tourism programs to the travellers. Thekkady in the East Division is home to the visitors' point. In the State of Kerala, it extends across three Revenue Districts: Idukki,

Pathanamthitta, and Kottayam. The Periyar Lake Reserve, Mount Plateau RF, Rattendon Valley RF, Ranni RF, and Gudrikkal RF are all included in the protected area.

Marshes, grasslands, moist deciduous forests, evergreen forests, eucalyptus plantations, streams, and reservoirs are the main habitat types in Periyar. Only a few studies and observations have been made, but they show that grasslands and marshy regions are heavily used by herbivores, which leads to a high concentration of predators in the ecosystem. Fire, weed infestation, and the encroachment of woody vegetation are the main threats to the grasslands and marshy land. Old images taken at the dam site make it abundantly obvious that woody growth has invaded the meadows. Arboreal species like the Lion Tailed Macaque, Nilgiri langur, and Malabar giant squirrel mostly inhabit evergreen woods.

Conspicuous changes in the habitat since inception had taken place. Three cardamom estates were located inside the core at the time of PTR's establishment in 1978. In 1984, control of these properties was gained by PTR, and forests were allowed to regenerate. The eucalyptus trees that were planted previously under Grassland Afforestation Division (GLAD) on a 55 km² area failed in large parts. Slowly, the natural forests are returning to these locations. Due to rising pilgrimage and the Travancore Devaswom Board's (TDB) increasing requests for more lands for the infrastructure development of Sabarimala, the ecology around Sabarimala in the buffer of PTR is constantly under threat and habitat degradation is having a severe impact (Sukla, 2012).

A total area of 925 km² is notified as Periyar Tiger Reserve (PTR). Out of it 881 km² is its core zone and 44 km² is its buffer zone and have 26 tigers. According to FSI (2021), digitized boundary of PTR includes an area of 935.30 km². In that 176.05 km² is very dense forest, 500.51 km² is moderately dense forest, and 110.25 km² is open forest and have a total of 786.81 km², which is 84.12% of total forest cover with respect to area of digitized tiger reserve boundary. And in 2011 total area digitized was 808.18 km². There is a change in 21.37 km² to the PTR when compared to 2011 and 2021 (FSI, 2021). Periyar has a wonderful biodiversity and a beautiful terrain, but its mega values are intricately entangled with mega developmental problems related to interstate fighting, tourism, and pilgrimage. These results are the key factor which point out to the relevance to do the landscape fragmentation analysis to this particular tiger reserve.

2.3 FOREST MANAGEMENT AND REMOTE SENSING

For its beneficial effects against global warming, the preservation of ecological variety, and the protection of indigenous peoples, forest conservation is essential. Protecting forested regions improves the management of natural resources, such as fresh water, which makes up 75% of the world's supply, and boosts agricultural productivity (Abad *et al.*, 2020). Remote sensing is the process of gathering and analysing data to learn more about forests without having the devices required to do so in close proximity to the forests themselves (Cochran *et al.*, 2020). In fact, remote sensing enhance forest management, which is the process of organising and carrying out procedures for the administration in order to achieve environmental, economic, social, and cultural goals. As a matter of fact, remote sensing is an important tool in forest management for characterising the three-dimensional structure of forests, mapping the distribution of forest ecosystems, analysing and estimating forest biomass, assessing forest damage using deep learning on high-resolution remote sensing data, detecting forest fires using novel remote sensing techniques, and more (Hamdi *et al.*, 2019, Lechner *et al.*, 2020, Santi *et al.*, 2020, Barmpoutis *et al.*, 2020). Ecosystems can be assessed using satellite photos, and the health and integrity of these ecosystems can be assessed using spectral indices. Currently available multispectral sensors come in a broad range, allowing for improved investigation of forest systems and ecosystem services.

To ensure a synoptic overview of the landscape at all scales, from the local to the global, satellite remote sensing offers enormous possibilities in this respect. The electromagnetic spectrum may also be captured outside of the visible range by satellite-based remote sensing instruments, with the ability to divide the whole spectrum into several bands. This enables the extraction of information about the variability of the earth's surface due to the reflective property of the earth's surface to the different electromagnetic wavelengths (Roy and Roy, 2010). The effective planning and implementation of policies are made possible by GIS, which can display information on both natural and manmade created resources in geographical domains. The ability to examine forest fragmentation and its effects on greenhouse gas emissions, biodiversity, economics, and water quality using land-cover maps created from satellite photography is exceptionally excellent (Kurt *et al.*, 2000).

The Geographic Information System is a potent tool that allows for the user-friendly storage, organization, and retrieval of geographical data. A possible tool for environmental management is the combination of satellite remote sensing data with auxiliary data in a GIS context together with GPS data. A new term, geoinformatics, has been created by fusing the GIS with information technology (IT). Organization, creation, and administration of

geospatial data; spatial modelling and data analysis; and development and incorporation of computer tools for the visualization and analysis of real-time geospatial problems in decision-making processes are the three main goals of geoinformatics (Roy and Roy, 2010).

Normalized Difference Vegetation Index (NDVI) is one of the widely accepted approaches to assess vegetation. The NDVI measures the equilibrium between the energy absorbed and the energy released by earthly objects. This index establishes a value for how green the region is when applied to plant communities, that is, the amount of vegetation present in a given area and its health or vigour of growth (Tovar, 2012). Data on vegetation biophysical features can be extracted from electromagnetic spectrum measurements in the visible, near-infrared, and mid-infrared ranges (EMS). The NDVI method is based on the observation that healthy vegetation has high reflectance in the NIR due to internal reflectance by the mesophyll spongy tissue of green leaves and poor reflectance in the visible region of the EMS due to Chlorophyll and other pigment absorption. Data on vegetation biophysical features can be extracted from electromagnetic spectrum measurements in the visible, near-infrared, and mid-infrared ranges (EMS). The NDVI method is based on the observation that healthy vegetation has high reflectance in the NIR due to internal reflectance by the mesophyll spongy tissue of green leaves and poor reflectance in the visible region of the EMS due to Chlorophyll and other pigment absorption. Red to NIR band ratios of a sensor system can be used to determine NDVI. Because of the strong reflectance in the NIR region of the EMS, NDVI values vary from -1 to +1, and healthy vegetation is represented by high NDVI values between 0.1 and 1. Due to the fact that water absorbs electromagnetic energy, non-vegetated surfaces like water bodies have negative NDVI values. Due to their strong reflectivity in both the visible and NIR spectrums of EMS, bare earth surfaces have NDVI values that are closest to 0 (Nath, 2014).

2.4 FRAGMENTATION OF LANDSCAPES

Ecologists concur that the quantity and quality of habitat have a significant impact on the geographical distribution and abundance of species, as well as the richness of species in communities. The fact that habitat loss is the primary factor contributing to global biodiversity decline emphasises the crucial role that habitat plays in regulating species richness. Fragmentation frequently occurs in conjunction with habitat loss (Hanski, 2015). As a result of growing issues regarding biodiversity loss, researchers are looking for novel strategies to manage landscapes at various spatial and temporal dimensions. A plethora of

analytical techniques are now accessible for analysing and managing landscapes due to the emergence of GIS (geographic information systems) technology. Public land management entities have started to understand the necessity of managing natural resources at the landscape scale in response to this rising theoretical and empirical backing as well as technical capabilities. Forman and Godron (1986) cited by Mobaied *et al.* (2016) defines landscape as a “heterogeneous land area composed of a cluster of interacting ecosystems that is repeated in similar form throughout.” A landscape is composed typically of several types of landscape elements (patches). The smallest ecologically different landscape feature in a landscape mapping and classifying system is patch. According to Turner (1989), “patch is as an area of homogeneous cover type that differs from its surroundings”. It is possible to describe habitat fragmentation as the process of destroying habitat and dispersing the remaining components throughout the newly formed terrain. Fragmentation is the breakdown into small, geographically separated patches, separated by land that is unsuitable for breeding, finding food, or finding shelter for a species that is limited to the original kind of habitat. As a result of this disintegration process, fragmentation may also be seen as a pattern. It may thus be conceptualised functionally as a geographically dispersed collection of habitat patches that are differentiated by the size, form, and arrangement of the patches as well as by how easily individuals of a specific species can migrate over the intermediate land (Opdam *et al.*, 1993). Forest fragmentation consists of two interdependent elements: forest loss and changes in spatial configuration (Long *et al.*, 2010). These two factors can be clearly assessed in this study.

2.4.1 Effects of Forest Fragmentation

Fragmentation process alters the composition, structure, and function of the landscape against a mosaic of natural patches produced by shifting landforms and natural disturbances. A major focus of ecological studies is the evolution and dynamics of spatial heterogeneity in landscapes, particularly the consequences of the transformation of natural ecosystems into human-dominated systems like agriculture or urban land use (Jaeger *et al.*, 2016). When a natural habitat in a landscape (like the forest) is altered, both its composition (the extent of the forest) and its layout (the spatial arrangement of the patches) change. Fragmentation is the term for this conversion (Clark, 2010). The extent of habitat fragmentation has a significant impact on the long-term viability of all ecosystems, communities, and species populations. The extent and spatial arrangement of animal habitats have changed as a result of habitat loss, degradation, fragmentation, conversion, and overexploitation of natural resources in

landscapes dominated by humans. This has significant implications for the preservation of biological diversity (Rameshan *et al.*, 2014). Forest loss and fragmentation affect the sustainability of ecological products and services provided by forest area and directly threaten biodiversity (Kurt *et al.*, 2000).

2.4.2 Forest Fragmentation Analysis

Landscapes are identified by the spatial relationships between their individual parts, which can be described by both their composition and configuration (also known as the "landscape pattern" or "landscape physiognomy") (Dunning *et al.*, 1992). The quantity and distribution of a specific patch type have relevance in many landscape ecological applications. In this kind of research, forest fragmentation analysis using geospatial tools is a suitable example. As a result of both natural processes and human land use activities, forest tracts gradually become fragmented into smaller, geometrically more complicated, and more isolated forest fragments, this phenomenon known as forest fragmentation (Harris, 1984). Between 2000 and 2012, there was a reported 2.3 million km² worldwide gross loss of forest cover (Hansen *et al.*, 2013). Reddy *et al.*, (2013) used landscape indicators to analyse India's national fragmentation. One major factor contributing to the decline of biodiversity is fragmentation (Fahrig, 2002).

2.4.3 Fragmentation Related Studies in PTR

This formerly continuous stretch of forest has been split into three forest complexes: Anamalai (5127 km²), Periyar (3678 km²), and Agasthyamalai (2112 km²). These three forest complexes each contain sizable, relatively contiguous stretches of legally protected habitat, though anthropogenic threats still exist. The two intervening human-dominated landscapes, Anamalai-Periyar (2050 km²) and Periyar-Agasthyamalai (346 km²), have seen significant habitat loss and fragmentation over time. Both the continuous forest complexes and the landscapes with a high human presence showed a variety of anthropogenic activity. However, hazards are more prevalent relative to other factors in human-dominated landscapes, such as logging, animal grazing, and road and rail networks (Pillai *et al.*, 2011). This study focuses in to the necessity to analyse and to check the fragmentation statistics of PTR and to check its variability inside the reserve and outside.

2.5 FRAGSTATS

Landscape structure can be measured using the spatial pattern analysis tool, FRAGSTATS. The landscape under examination can represent any spatial phenomenon and is user defined. The user must establish a sound basis for defining and scaling the landscape (including the extent and grain of the landscape) as well as the system by which patches inside the landscape are classified and delineated. FRAGSTATS takes into account the areal extent and spatial distribution of patches (i.e., polygons on map coverage) within a landscape. Three types of metrics are computed by FRAGSTATS. For a given landscape mosaic, FRAGSTATS computes a number of statistics for the mosaic's individual patches, patch types (classes), and overall landscape mosaic. Class indices can be considered of as indices of fragmentation for each patch type since they individually quantify the quantity and distribution of each type of patch in the landscape. Four output files are produced by FRAGSTATS by default. The extensions, .full, .patch, .class, and .land are added by FRAGSTATS to the base name that the user specifies for the output files (McGarigal and Marks, 1995). Landscape structure, function, and evolution may be understood better by the study of landscape-level and class-level metrics (Sing *et al.*, 2014). Many studies have been conducted all over the world to analyse the fragmentation and its pattern for the better landscape and forest management (Li *et al.*, 2001, Kamusoko and Aniya, 2007, Singh *et al.*, 2014, and Srinivasan *et al.*, 2022)

2.5.1 Area Metrics

Class area (CA) is a measurement of the composition of the landscape, specifically the proportion of each type of patch in the landscape. This is a crucial metric for a number of ecological applications. For instance, quantitative habitat loss is a significant consequence of habitat fragmentation. It is crucial to understand how much of the target patch type (habitat) is present in the landscape while studying forest fragmentation. As the patch type becomes more and more rare in the terrain, CA gets closer to zero. When a single patch type makes up the entire landscape, or when the entire image is made up of a single patch, $CA = TA$.

Total landscape area (TA) is significant because it determines the extent of the landscape, even though it frequently lacks significant interpretive value for assessing landscape structure. Numerous class and landscape metrics are calculated using total landscape area as well. Since total landscape area is significant regardless of whether the main focus is on class or landscape indices, it is included as both a class and landscape index (and included in the respective output files) (Mcgarigal, 2015).

These measurements measure area in hectares, although it is frequently preferable to measure area in terms of a percentage of the total area of the landscape. Therefore, FRAGSTATS calculates the percentage of landscape (%LAND) occupied by each patch type at the class level. It is listed as a patch attribute because the presence of many other comparable patches in the surrounding area can affect some of the ecological characteristics of the patches. When the corresponding patch type (class) in the landscape gets progressively less common, %LAND approaches 0. When a single patch type makes up the entire landscape, or when the entire image is made up of a single patch, %LAND = 100.

The percentage of the overall landscape area occupied by the largest patch is calculated by FRAGSTATS at the class and landscape levels using the largest patch index (LPI). When the largest patch of the relevant patch type shrinks steadily, LPI approaches 0. When a single patch of the relevant patch type covers the entire terrain, or when the largest patch makes up 100% of the landscape, LPI = 100 (McGarigal and Marks, 1995).

2.5.2 Patch Density and Size Metrics

Depending on the landscape context, the number of patches (NP) of a specific habitat type may influence a slew of ecological processes. Habitat fragments that are highly fragmented patch types may experience higher rates of disturbance than contiguous habitats. If there is only one patch of the corresponding type in the landscape, or if the class only consists of one patch, then $NP = 1$. When a landscape just has one patch, $NP = 1$ at the landscape level. A simple, fundamental component of landscape organisation is patch density (PD). The essential function of an index is the same for both patch density and patch number; however patch density represents patch number by per unit area, making comparisons between landscapes of different sizes easier.

Of course, patch density and number of patches transmit the same information if the entire landscape area is kept constant. Patch density for a specific patch type could function as a good fragmentation index if the quantity of patches, rather than their size or location, is particularly significant. A landscape with a higher density of patches of a target patch type would be regarded as more fragmented than a landscape with a lower density of such patches, assuming class area remained constant. Similar to this, a decent heterogeneity metric may be the density of patches throughout the entire landscape mosaic because a landscape with more patches would likely have higher spatial heterogeneity (Mcgarigal, 2015).

2.5.3 Interspersion Metrics

Interspersion and juxtaposition index (IJI), which is based on "patch" adjacencies and works with both vector and raster images, is applicable at both the class and landscape levels. Each patch is assessed for its proximity to all other patch kind; like adjacencies are not feasible because a patch cannot be close to another patch of the same type. Internal cells in raster pictures are not taken into account; only the patch perimeters are used to calculate the overall length of each distinct edge type. Considering that this index measures "patch" adjacency rather than "cell" adjacency.

The interspersion index measures the extent to which patch types are interspersed. Higher values result from landscapes in which the patch types are well interspersed (equally adjacent to each other), whereas lower values characterize landscapes in which the patch types are poorly interspersed (disproportionate distribution of patch type adjacencies). The interspersion index is not directly affected by the number, size, contiguity, or dispersion of patches per se. The interspersion index is a relative index representing the observed level of interspersion as a percentage of the maximum possible given the total number of patch types. The interspersion and juxtaposition index can be applied at both the class and landscape levels. At the class level, this index measures the juxta-positioning of a focal patch type with all others and does not reflect the interspersion of other patch types. The interspersion and juxtaposition index is not affected because it considers only patch edges. IJI approaches 0 when the corresponding patch type is adjacent to only 1 other patch type and the number of patch types increases. $IJI = 100$ when the corresponding patch type is equally adjacent to all other patch types (maximally interspersed and juxtaposed to other patch types). IJI is undefined and reported as "NA" in the "basename".full file and as a dot "." in the "basename".class file if the number of patch types is less than 3 (McGarigal and Marks, 1995).

2.6 CONSERVATIONAL MEASURES

Since 1996, the Supreme Court of India has prohibited all types of clear-felling in Indian forests, leading to severe conservation measures and community forest management (Rosencranz and Lele 2008). As part of the 2008 National Action Plan on Climate Change, the Green India Mission promoted planting trees to cover one third of the country's land area (Rosencranz and Lele 2008). Protected areas are created in accordance with the Wildlife Protection Act of 1972, and adjustments have occasionally been made that are grounded in reality and are geared toward managing protected areas. It demonstrates India's dedication to

the 2020 Aichi biodiversity objective in the ‘Strategic Plan for Biodiversity 2011–2020 and the Aichi Targets’, i.e., By 2020, degradation and fragmentation will have greatly decreased, and the rate of loss of all natural ecosystems, including forests, will have been at least halved and, where possible, brought down to zero.

Considering the conservational commendations to PTR, the National Tiger Conservation Authority presented the National Award to Periyar Tiger Reserve in 2016 for having the best anti-poaching camps (NTCA). Periyar Tiger Reserve was ranked top in the most current Management Effectiveness Evaluation Report of Tiger Reserves, which was published by NTCA in 2018 (GoK, 2019).

MATERIALS AND METHODS



MATERIALS AND METHOD

The present study tries to evaluate;

- The forest fragmentation in and around Periyar Tiger Reserve by analyzing tri-temporal satellite derived data sets.
- And to analyze the land use land cover change in the study region.

STUDY AREA

The proposed study area is Periyar Tiger Reserve (PTR) (Figure 1) with an altitude ranges from 900 to 2000m that includes tropical evergreen forests, tropical semi-evergreen forests, moist deciduous forests, grasslands and eucalyptus plantations (GoK, 2021). Periyar Tiger Reserve (PTR) is one of the most well-known protected areas (PAs) and a significant part of India's Western Ghats because of its extensive biodiversity. The Reserve is located in the Western Ghats' 5-B Zone. PTR is located in the Southern Western Ghats between latitudes 9° 17' 56.04" and 9° 37' 10.2" N and longitudes 76° 56' 12.12" and 77° 25' 5.52" E. The major portion of the reserve forms the catchment of River Periyar and the rest is that of River Pamba. Administratively, PTR falls in Idukki, Kottayam and Pathanamthitta Districts of Kerala. Periyar is divided into two divisions: Periyar East with three ranges under it Periyar (376 km²), Thekkady (99 km²) and Vallakadavu Range (143 km²) and Periyar West with two ranges under it Azutha Range (68 km²) and Pampa (91 km²).

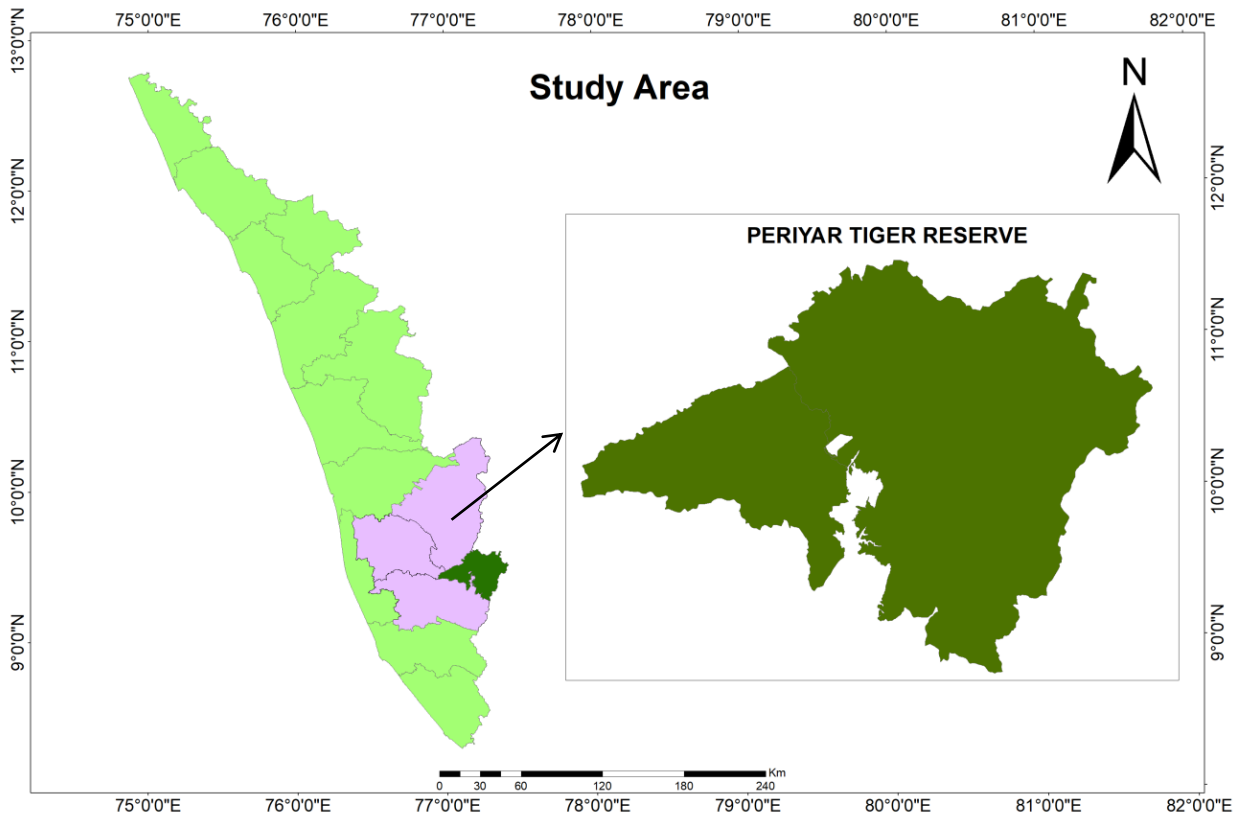


Figure 1: Study area

Based on the available literatures, PTR which forms about 10% of total forest area in the State, contains about 41% (1985 species) of the flowering plants of Kerala (4801 species). Out of the 1985 flowering plants, 519 species (about 26%) are endemic to southern Western Ghats (WG) and 149 species under various threat categories (Ramachandra *et al.*, 2021). PTR is abode of many endemic species with great diversity of flora and fauna. Among the flora, dicotyledons are represented by 1450 species under 621 genera belonging to 124 families and monocotyledons by 530 species under 210 genera in 23 families. Forests of PTR support several endangered faunal species viz., tiger, leopard, elephant, gaur, sambar, lion-tailed macaque, Nilgiri langur, Nilgiri tahr, Nilgiri marten, sloth bear, great Indian hornbill and Ceylon frogmouth (Sasidharan, 1998). PTR has recorded 66 species of mammals (7 are endemic to WG), 323 species of birds (14 are endemic to WG), 48 species of reptiles (17 are endemic to WG), 29 species of amphibians (12 are endemic to WG), 45 species of fishes (16 are endemic to WG including 7 endemic to Periyar) and 167 species of butterflies (20 are endemic to WG) (Sukla, 2012). According to the Kerala forest and wildlife department, administration report of 2018-2019, in 1950 Periyar WLS (Tiger Reserve) has an area of 925 km² and in 1982, 350 km² area was included in Periyar Wildlife Sanctuary as Periyar National Park.

3.2 IMAGE PRE-PROCESSING

Landsat TM Mosaic, Landsat 7, and Landsat 8 satellite imagery with better visualization (less than 15% cloud cover) from the USGS earth explorer (<https://earthexplorer.usgs.gov/>) were selected for the study (Figure 2). Datum was set to WGS 84 and referenced to Universal Transverse Mercator (UTM) zone 43 north. Geometric correction via geo-referencing conducted for eliminating the geometric distortion, particularly for change detection analysis of the area. Digital image processing includes procedures for pre-processing, enhancement and information extraction. Image import and Image stacking were the first step which was done after the data acquisition. Image processing requires several steps for the better identification of the image features. It is a kind of numerical manipulation of digital images including the procedures for image enhancement and information extraction were carried out. Spectral enhancement has been performed on the three selected satellite images before the classification and interpretation steps. After layer stacking, FCC creation and image enhancement of the particular Landsat imageries and visual Image interpretation have done along with Google earth synchronization and Bhuvan-NRSC. 1 km buffer was created and extracted from images of each year other than that of the selected area of PTR.

3.3 NDVI

NDVI is thought to be representative of vegetation biomass. Vegetation index images were created for each year, 1987, 2000 and 2020, using the NDVI, from the selected Landsat images of same season (January to April), which is represented as equation (1) for the year 2020 and (2) for the years 2000 and 1987.

$$NDVI = \frac{\text{Band 5} - \text{Band 4}}{\text{Band 5} + \text{Band 4}} \quad (1)$$

$$NDVI = \frac{\text{Band 4} - \text{Band 3}}{\text{Band 4} + \text{Band 3}} \quad (2)$$

From the obtained range of values, forest and non- forest areas can be distinguished. Also by comparing the values obtained for each year, change of vegetation of each year can also be analysed (Southworth *et al.*, 2004).

3.4 FOCUS GROUP DISCUSSION (FGD)

Focus group discussions are frequently used as a qualitative technique to fully understand social topics. Instead of drawing data from a statistically representative sample of a larger population, the technique aims to get information from a specific set of individuals. The first step in the process is to identify the main objective of the study and its core research goals. A set of ethically sound questions (also known as a schedule or script) is created based on the study objectives to serve as a guide for each focus group discussion session. The facilitator plays a key role in the discussion by fostering pleasant and comfortable surroundings for new participants as well as managing existing relationships. Where analyses can be challenging, focus group discussions typically produce both qualitative and observational data. As part of the focus group discussion data were collected from different homogenous groups having members from 4 to 15 (Nyumba *et al.*, 2018). As part of the study, FGD were conducted with various stakeholders viz., forest officials, EDC staffs, and other forest dependent communities inside PTR.

3.5 LAND USE LAND COVER CHANGE (LULCC)

As a primary analysis unsupervised classification has done using ArcMap 10.4.1. Using the obtained results ground truthing was conducted in each divisions of the reserve. Along with the available ground truth points supervised classification was done using ArcMap 10.4.1. Supervised classification involves on-screen digitization of polygons on training sites. Signature files for different classes in the region of interest were prepared. By incorporating all available data to promote accuracy hybrid classification was done in ERDAS Imagine 2014 software. Hybrid classification techniques (a combination of visual interpretation, unsupervised classification, supervised classification and NDVI) were used in mapping of land cover (Reddy *et al.*, 2013). Likewise hybrid classification was prepared for each year. For monitoring and evaluating the land use land cover change of PTR two type classifications of maps were prepared.

- Land use land cover map for all the three years and for its buffer prepared include classes; Dense forest, Open forest, Grassland, Rocky/ barren land, Water body, Agriculture and Settlement.
- And forest classification based land cover map for all the three years prepared include classes; Evergreen forest, Semi evergreen forest, Moist deciduous forest, Grassland, Rocky/ barren land and Water body.

LULC prepared using the satellite images downloaded from USGS earth explorer for different years. 1987 LULC made from Landsat TM Mosaics, 2000 map from Landsat 7, having path; 144 and 143 and row; 053 and 054. 3 satellite images were mosaicked to obtain cloud free data of the area. For 2020 Landsat 8 images were taken, having the same path and row as that of Landsat 7. Here 2 images were mosaicked to obtain the data. Classes made for these maps include dense forest (tree canopy density of 40% and more), open forest (tree canopy density of 10% to 40%), grassland, rocky/ barren land, settlements (include all man made constructions), agriculture and water body.

3.5.1 Accuracy Assessment

The dependability of the classified map created from satellite imagery is thought to be most closely related to the accuracy estimation. The use of an error matrix or confusion matrix is the approach most frequently used for evaluating the reliability of a map (Munsi *et al.*, 2010). The mistakes of omission and commission were evaluated using the error matrix method. The degree to which the classified image accurately portrayed the actual characteristics on the ground was measured using the producer accuracy, user accuracy, overall accuracy, and kappa coefficient.

3.6 FRAGMENTATION ANALYSIS USING FRAGSTAT VERSION 4.2

A spatial pattern analysis programme for categorical maps developed by Kevin McGarigal and Eduard Ene. The landscape subject to analysis is user defined and can represent any spatial phenomenon. FRAGSTATS simply quantifies the areal extent and spatial configuration of patches within a landscape; it is incumbent upon the user to establish a sound basis for defining and scaling the landscape (including the extent and grain of the landscape) and the scheme upon which patches are classified and delineated. The output from FRAGSTATS is meaningful only if the landscape mosaic is meaningful relative to the phenomenon under consideration (McGarigal and Marks, 1995).

3.6.1 FRAGSTATS Computes 3 Groups of Metrics viz,

- a. Patch-level – nature of patches - Average size, size of core area.
- b. Class-level – nature of each type - Amount and distribution of each type
- c. Landscape-level – nature of the landscape - Pattern, configuration of entire mosaic, landscape -diversity, heterogeneity.

3.6.2 File creation in Fragstat 4.2

Weight files should be made, which are used for to analyze the different perimeter in the Fragstats model. For this, Text Editor like Microsoft Excel or in the other Editors are used. The File should be a Comma separated value file (.csv) Note FRAGSTATS uses the file extension .fcd for class descriptor files and will look for files with this extension by default when navigating. The .fcd extension is not mandatory, but using it can help keep files organized. Each record in the file should contain a numeric class (patch type) value, the character descriptor for that patches type, a logical status indicator, and a local background indicator. After making all the weight files, make Fragstats model. This method or model is repeated for every district in the landscape. Then the analysis was completed. Landscape evaluation was conducted using indices like CA, PLAND, NP, PD, LPI and IJI using Fragstat version 4.2 spatial analysts.

3.6.3 Various indices used for the present study

3.6.3.1 Total class area (CA) (Hectares)

CA equals the sum of the areas (m²) of all patches of the corresponding patch type, divided by 10,000 (to convert to hectares); **Total landscape area (TA)** equals the area (m²) of the landscape, divided by 10,000 (to convert to hectares). The area of any background patches in the landscape is excluded by TA.

3.6.3.2 Percentage of Landscape (PLAND) (percent)

PLAND equals the sum of the areas (m²) of all patches of the corresponding patch type, divided by total landscape area (m²), multiplied by 100 (to convert to a percentage); in other words, PLAND equals the percentage the landscape comprised of the corresponding patch type. It is useful in computing the proportional abundance for each of the patch type across the landscape.

3.6.3.3 Largest patch index (LPI) (percent)

In class metrics, LPI equals the area (m²) of the largest patch of the corresponding patch type divided by total landscape area (m²), multiplied by 100 (to convert to a percentage). In Landscape metrics, LPI equals the area (m²) of the largest patch in the landscape divided by total landscape area (m²), multiplied by 100 (to convert to a

percentage). LPI, therefore, is the proportion of the landscape that is made up of the biggest patch.

3.6.3.4 Number of patches (NP) (unit-none)

NP equals the number of patches of the corresponding patch type (class). In landscape level, NP equals the number of patches in the landscape. NP does not include any background patches within the landscape or patches in the landscape border. Number of patches of a particular patch type is a simple measure of the extent of subdivision or fragmentation of the patch type. Of course, if total landscape area and class area are held constant, then number of patches conveys the same information as patch density or mean patch size and may be a useful index to interpret. Number of patches is probably most valuable, however, as the basis for computing other, more understandable, metrics. Note that the choice of the 4- neighbour or 8-neighbor rule for delineating patches will have an impact on this metric.

3.6.3.5 Patch density (PD) (Number per 100 hectares)

PD equals the number of patches of the corresponding patch type divided by total landscape area (m²), multiplied by 10,000 and 100 (to convert to 100 hectares) in the class level. In landscape level PD equals the number of patches in the landscape divided by total landscape area, multiplied by 10,000 and 100 (to convert to 100 hectares). Note that the choice of the 4-neighbor or 8-neighbor rule for delineating patches will have an impact on this metric. A class with a higher patch density is likely to be more fragmented since it is separated into multiple patches.

3.6.3.6 Interspersion and juxtaposition index (IJI) (percent)

IJI equals minus the sum of the length (m) of each unique edge type involving the corresponding patch type divided by the total length (m) of edge (m) involving the same type, multiplied by the logarithm of the same quantity, summed over each unique edge type; divided by the logarithm of the number of patch types minus 1; multiplied by 100 (to convert to a percentage). In other words, the observed interspersion over the maximum possible interspersion for the given number of patch types. IJI considers all patch types present on an image, including any present in the landscape border (McGarigal and Marks, 1995).

3.7 MANN-WHITNEY U TEST

As recommended by Ojoyi *et al.*, (2016), Mann-Whitney U test was used to check and evaluate significance of differences among patch areas in all the years.

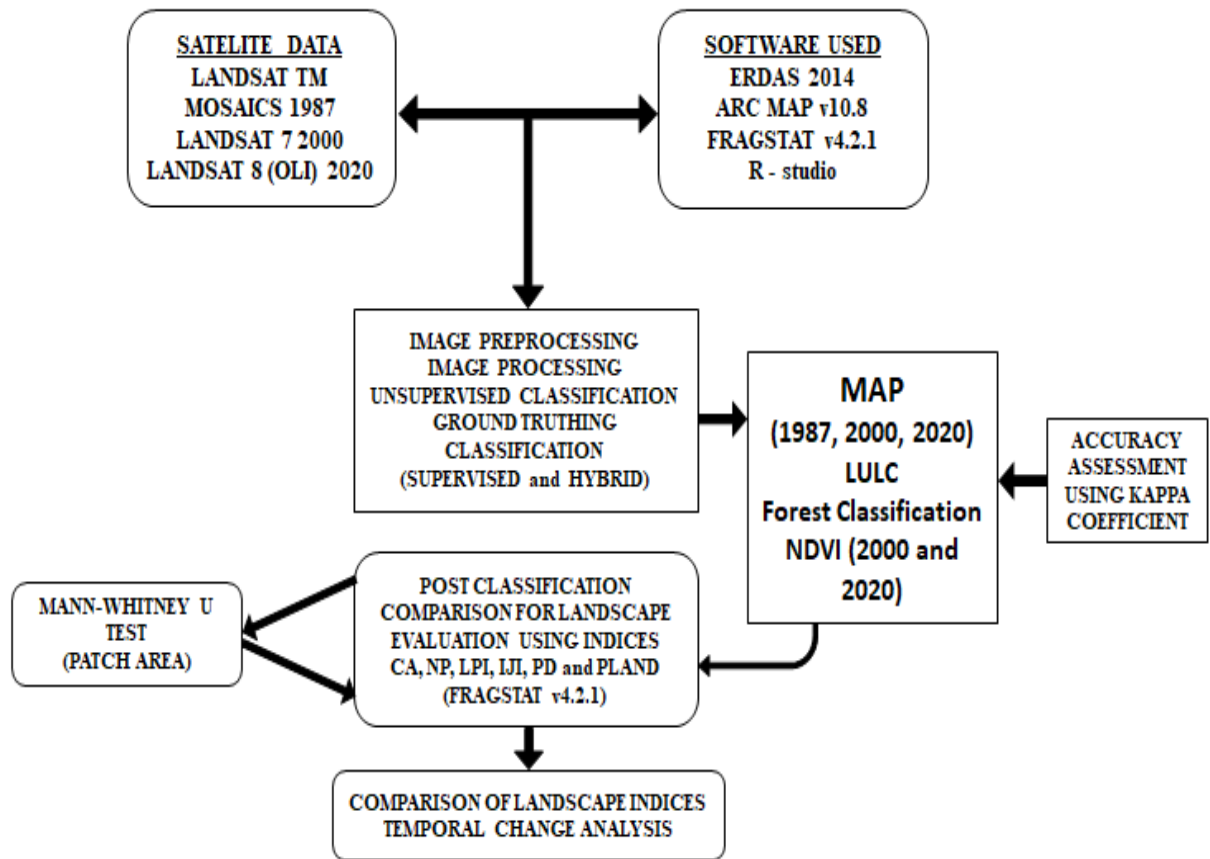


Figure 2: Flow chart of the study

RESULTS



RESULTS

4.1 NDVI

According to the data obtained from NDVI maps for the years 2000 (Figure 3) and 2020 (Figure 4), 0.53 in 2000 increased to 0.61 in 2020 (Table 1).

Table 1: Values of NDVI of the study area for the years 2000 and 2020

	2000	2020
High value (Max. +1)	0.53	0.61
Low value (Max. -1)	-0.46	-0.10
Mean	0.31	0.33

For the NDVI 2000, obtained mean value is 0.31 and standard deviation is 0.06. Mean value obtained for 2020 NDVI is 0.33 standard deviation is 0.08.

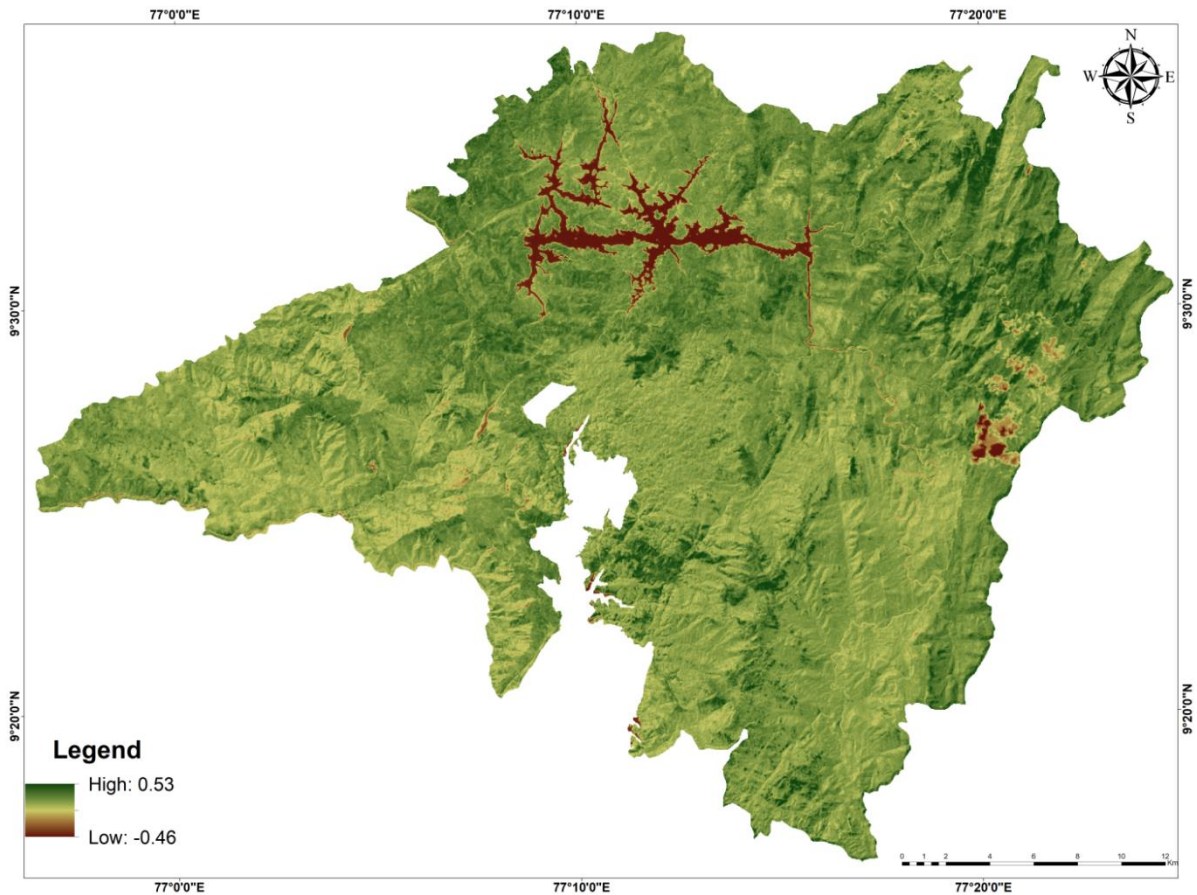


Figure 3: NDVI of PTR (inside) region of 2000

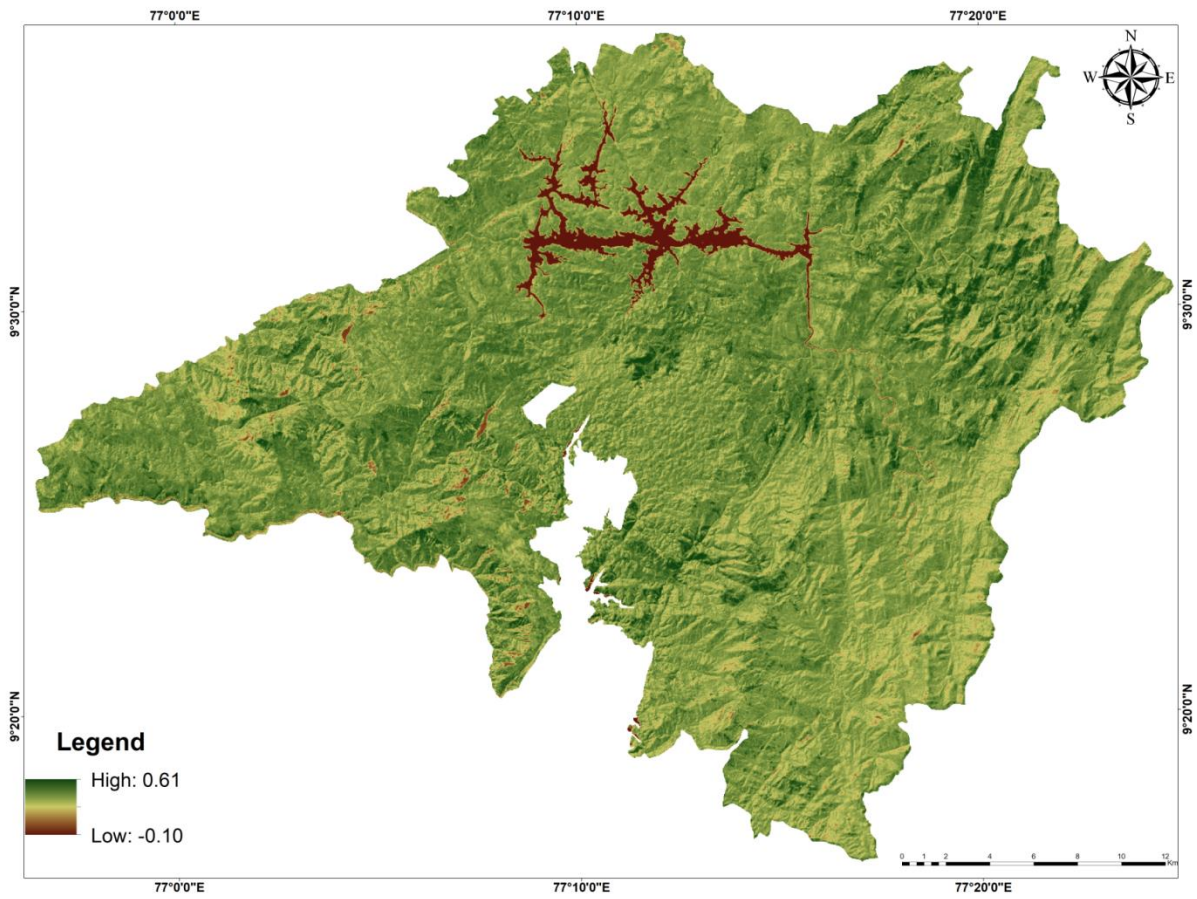


Figure 4: NDVI of PTR (inside) region of 2020

4.2 FOCUS GROUP DISCUSSION (FGD)

As part of the study, FGD were conducted with various stakeholders viz., watchers, plantation workers, and other forest dependent communities (Plate 1 and 2). Even though a few developmental activities occurred, it doesn't make a major cause for fragmentation (Figure 5). But some natural calamities were also reported by them. 1996 forest fire which affect approximate 5-8 ha of area in forest and landslide occurred in 2000 are some among them. Plantation gets converted to forest area, especially under the area by Kerala Forest Development Cooperation (KFDC). Along with that active afforestation activity is also happening (Figure 6). Forest dependent communities collect NTFP as their livelihood.

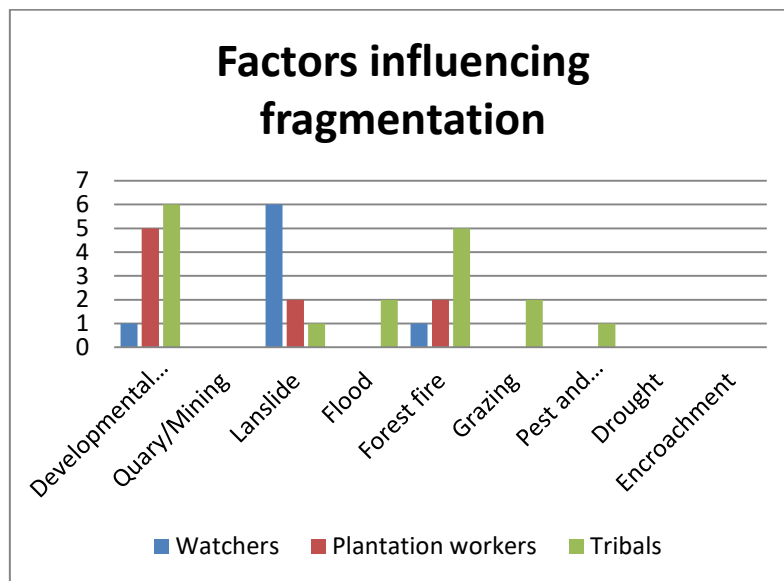


Figure 5: Factors influencing fragmentation

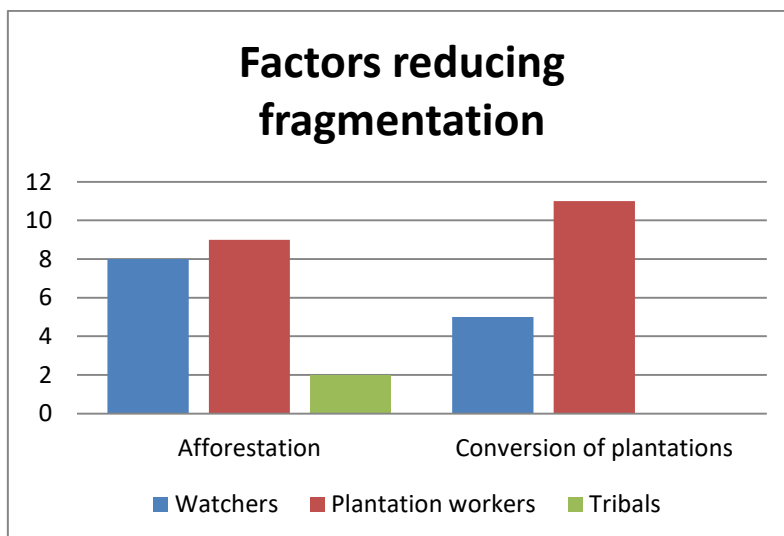


Figure 6: Factors reducing fragmentation



Plate 1: FGD conducted with forest guards



Plate 2: FGD conducted with forest dependant community

4.3 LAND USE AND LAND COVER DISTRIBUTION

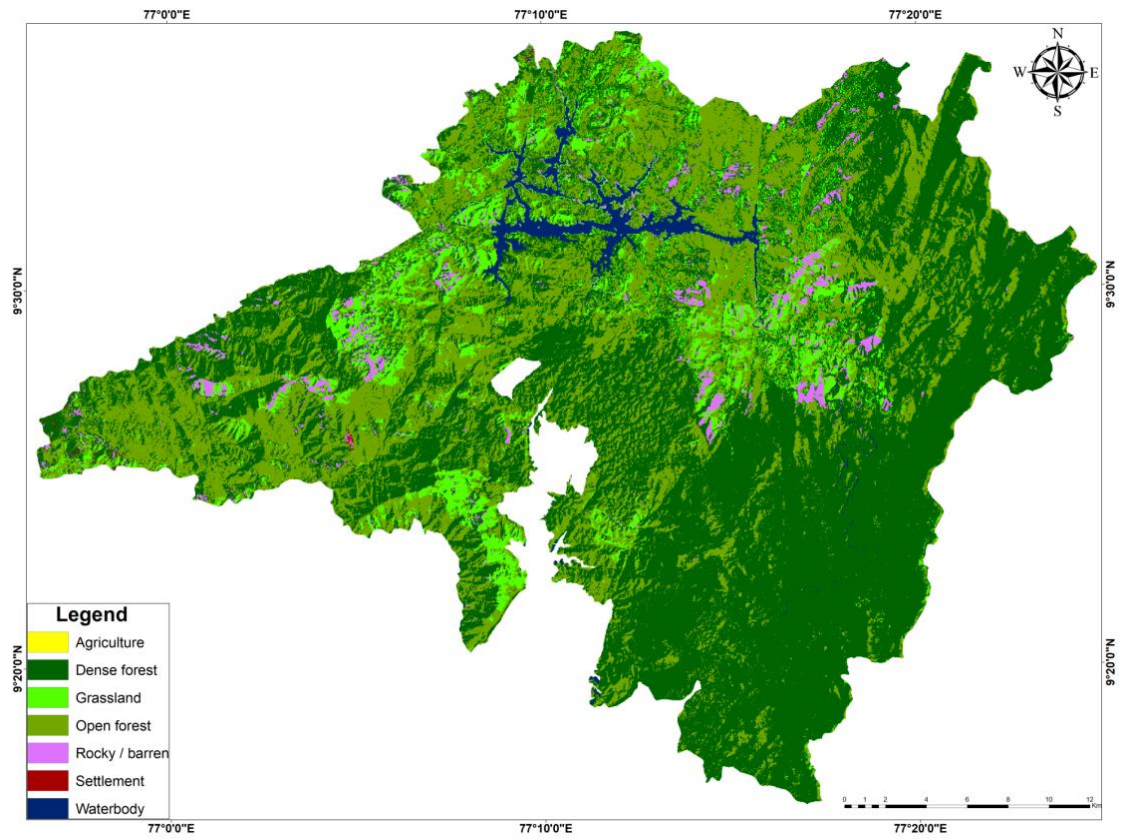


Figure 7: LULC classification of PTR (inside) in 1987

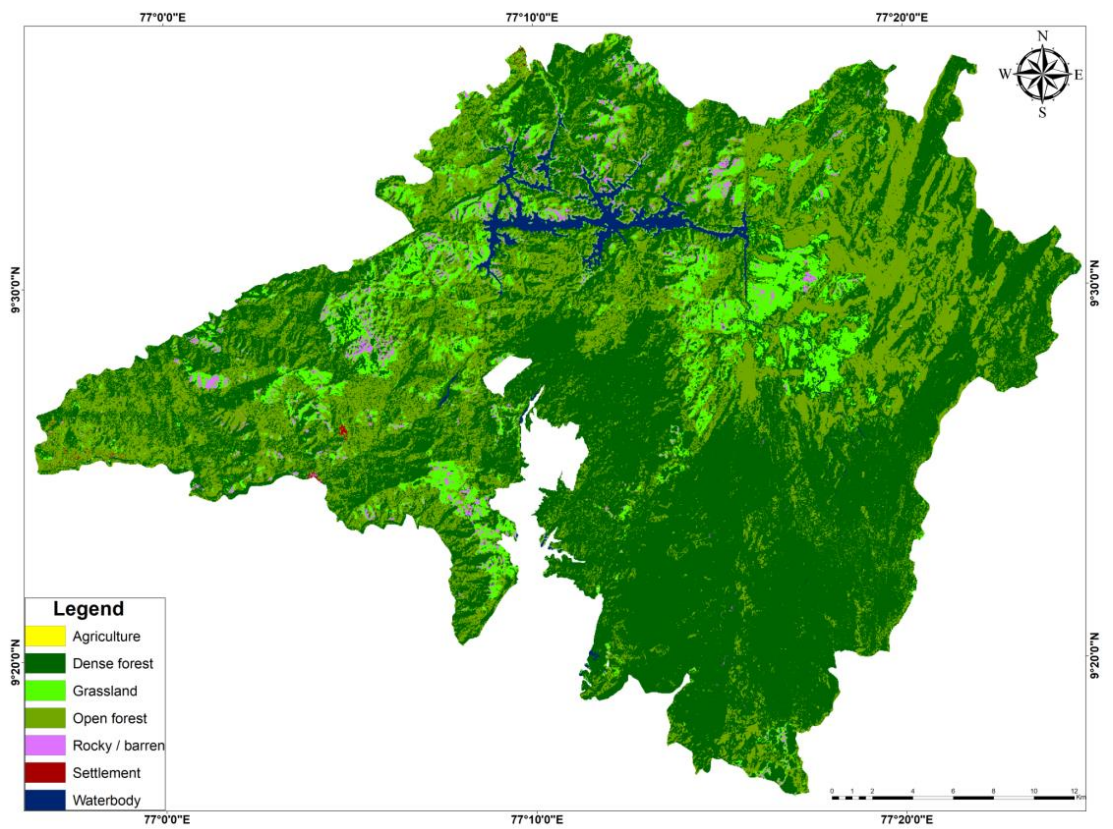


Figure 8: LULC classification of PTR (inside) in 2000

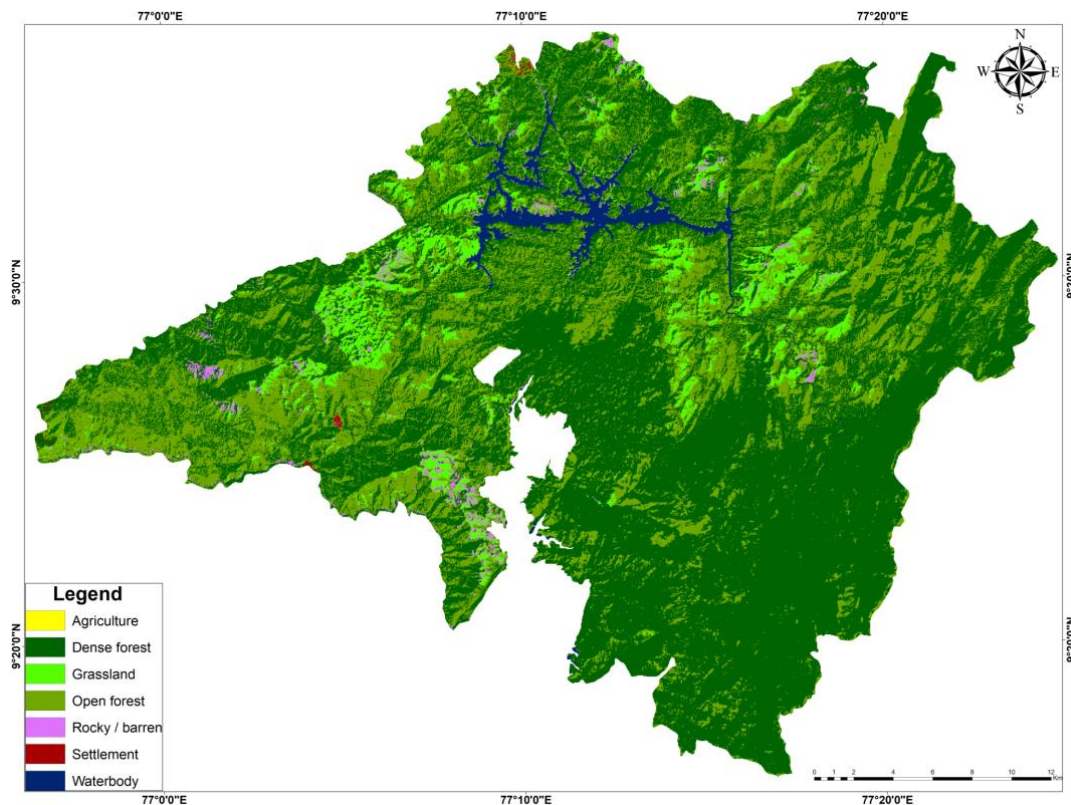


Figure 9: LULC classification of PTR (inside) in 2020

Inside the PTR, LULC map shows a gradual and significant increase in the area of dense forest from 1987 (54.95%) (Figure 7, Table 2) to 2000 (57.61%) (Figure 8, Table 2) which is 24.94 km² (Table 3) and 2000 (57.61%), to 2020 (61.98%) (Figure 9) which is 40.93 km² (Table 3). An overall increase of 65.87 km² was observed from 1987 to 2020 (Table 3).

Table 2: LULC of PTR (inside) of the years 1987, 2000 and 2020

LULC	1987 (km ²)	%	2000 (km ²)	%	2020 (km ²)	%
Water body	18.54	1.98	16.35	1.75	17.33	1.86
Dense forest	513.35	54.95	538.29	57.61	579.22	61.98
Open forest	296.83	31.77	279.14	29.88	277.18	29.68
Rocky / Barren	22.76	2.44	16.47	1.76	12.09	1.29
Agriculture	0	0	0	0	0	0
Settlement	0.35	0.04	0.59	0.06	0.86	0.09
Grassland	82.45	8.82	83.39	8.93	47.6	5.1
Total	934.28	100	934.28	100	934.28	100

Table 3: LULCC of area for the years 1987, 2000 and 2020 inside PTR

LULC	1987-2000 (km²)	2000-2020 (km²)	1987-2020 (km²)
Water body	-2.19	0.98	-1.21
Dense forest	24.94	40.93	65.87
Open forest	-17.69	-1.96	-19.65
Rocky / Barren	-6.29	-4.38	-10.67
Agriculture	0	0	0
Settlement	0.24	0.27	0.51
Grassland	0.94	-35.79	-34.85

Open forest and rocky or barren land show moderate decrease in the total area. A total of 19.65 km² and 10.67 km² of open forest and rocky or barren land respectively have decreased from 1987 to 2020 (Table 3). In the case of grassland from 1987 to 2000, 0.94 km² has increased but from 2000 to 2020 35.79 km² has decreased. An overall of 34.85 km² has decreased from 1987 to 2020 (Table 3). Land modification occurred in the settlement category shows a slight increment of 0.51 km² area. Here there is no remarkable area of agriculture land use. Even though water body shows a decrease of 2.19 km² from 1987 to 2000, from 2000 to 2020 it showed an increase of 0.98 km² area. By 2020, a total of 17.33 km² area of water body was noted in PTR (Table 2).

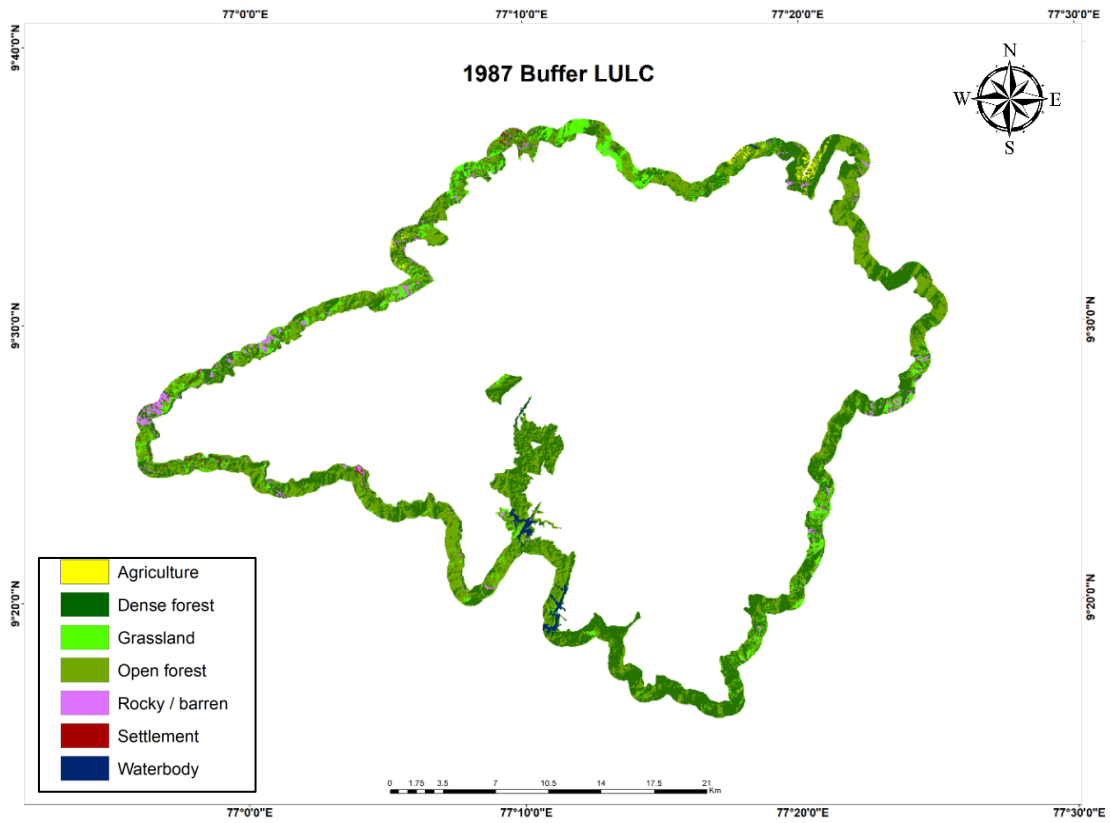


Figure 10: LULC classification of PTR (buffer) in 1987

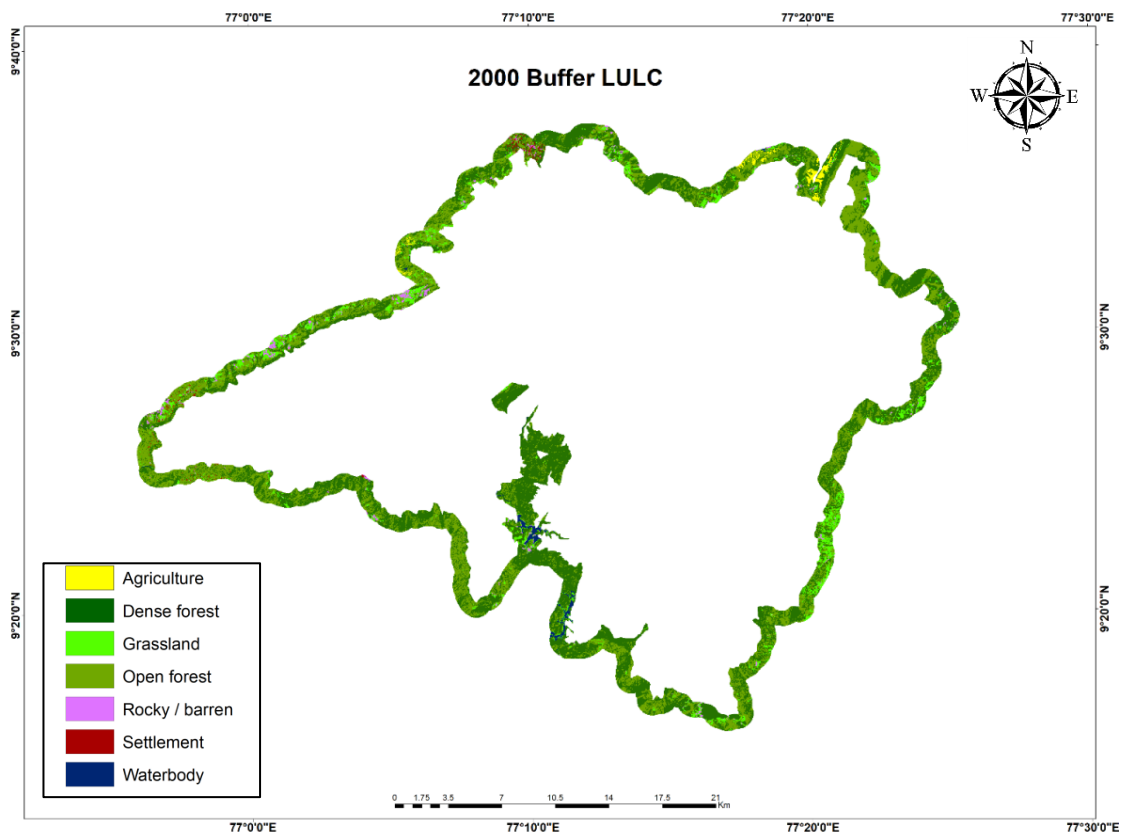


Figure 11: LULC classification of PTR (buffer) in 2000

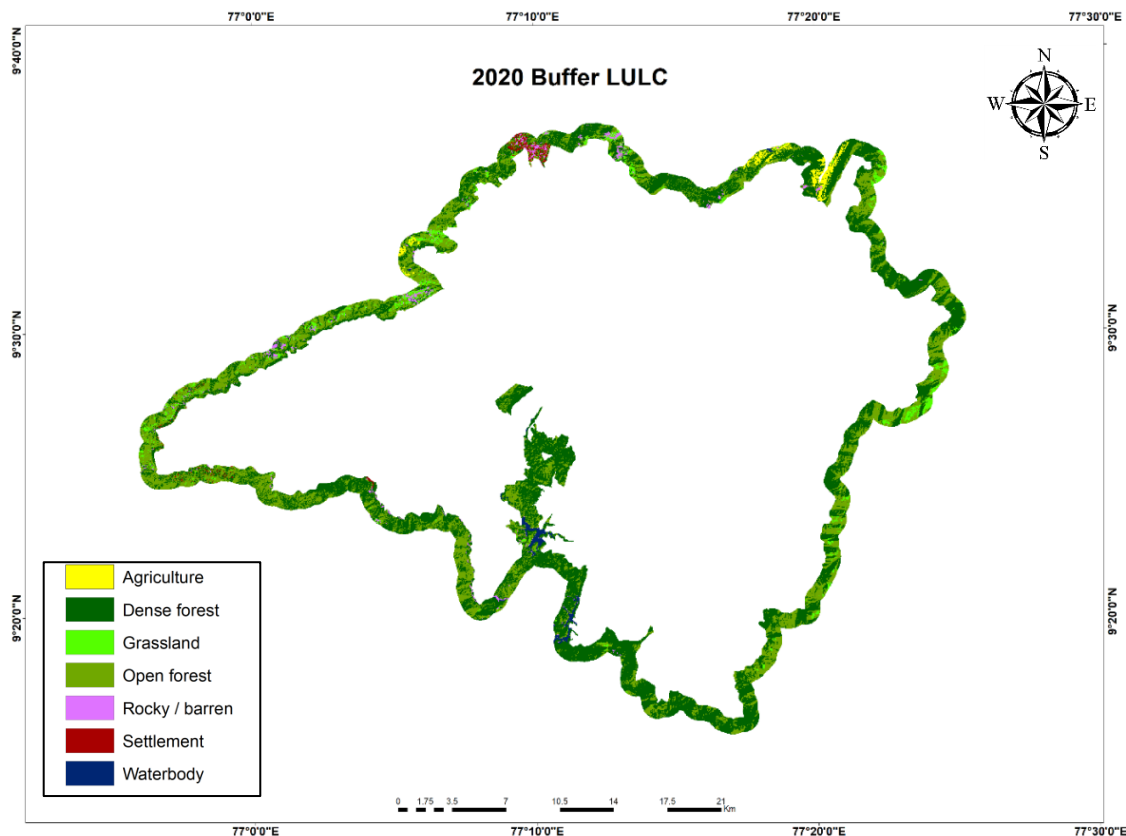


Figure 12: LULC classification of PTR (buffer) in 2020

Considering the 1 km buffer taken around PTR an area of 216.31 km² was classified (Table 4). Likewise, during the selected years (1987, 2000, and 2020), from the trend inside the PTR boundary, we can observe a consistent increase of area under dense vegetation (14 km² from 1987 to 2020) in the selected buffer area also (Table 5) (Figure 10, 11, and 12).

Table 4: LULC of PTR (buffer) for the year 1987, 2000 and 2020

LULC	1987 (km ²)	%	2000 (km ²)	%	2020 (km ²)	%
Water body	2.46	1.14	1.85	0.86	2.03	0.94
Dense vegetation	101.26	46.74	107.8	49.84	115.26	53.28
Open vegetation	81.83	37.88	80.76	37.34	78.84	36.45
Rocky / Barren	7.99	3.7	3.52	1.63	4.06	1.88
Agriculture	1.33	0.62	2.16	1	3.32	1.53
Settlement	0.54	0.25	0.99	0.46	1.68	0.78
Grassland	20.58	9.53	16.71	7.73	9.79	4.53
Total	216.31	100	216.31	100	216.31	100

Table 5: LULCC in area for the years 1987, 2000 and 2020 in PTR buffer

LULC	1987-2000 (km²)	2000-2020 (km²)	1987-2020 (km²)
Water body	-0.61	0.18	-0.43
Dense vegetation	6.54	7.46	14
Open vegetation	-1.07	-1.92	-2.99
Rocky / Barren	-4.47	0.54	-3.93
Agriculture	0.83	1.16	1.99
Settlement	0.45	0.69	1.14
Grassland	-3.87	-6.92	-10.79

An optimal decrease in the land area of open vegetation and grassland show the similarity of buffer to the study area. Opposite to the land use trend inside the PTR boundary, agriculture land use pattern show a notable increase in the area. 0.62% of agriculture land in 1987 changed to 1.53% in 2020. Likewise there is an increment of 1.14 km² in the settlement category. The agriculture and settlement classes in the selected buffer area show the substantial land modifications occurring in the nearby areas of PTR.

Table 6: Accuracy assessment of LULC map of 2020

Class No.	Land cover classes	Producer's accuracy (%)	User's accuracy (%)
1	Water body	100	100
2	Dense forest	85.71	85.71
3	Open forest	75	85.71
4	Agriculture	100	100
5	Grass land	83.33	71.42
6	Settlement	100	83.33
7	Rocky/ barren	71.42	83.33

The obtained kappa coefficient for the LULC map of 2020 is 0.84 and overall accuracy is 86.36% (Table 6).

4.4 FRAGMENTATION ANALYSIS

Fragmentation analysis was done using FRAGSTATS 4.2 software.

Table 7: Class level metrics (CA, PLAND and NP) for PTR of 1987, 2000 and 2020

TYPE	CA			PLAND			NP		
	1987	2000	2020	1987	2000	2020	1987	2000	2020
Dense forest	513.35	538.29	579.22	54.94	57.61	61.98	8269	7356	5299
Open forest	296.83	279.14	277.18	31.77	29.88	29.68	8708	11714	14520
Rocky/ barren	22.76	16.47	12.09	2.43	1.76	1.29	2746	2785	2882
Grassland	82.45	83.39	47.6	8.82	8.93	5.10	6511	4325	2803
Settlement	0.35	0.59	0.86	0.03	0.06	0.09	123	179	242
Water body	18.54	16.35	17.33	1.99	1.75	1.86	436	210	226
Agriculture	0	0	0	0.00	0	0.00	1	0	2
	934.28	934.28	934.28				26794	26569	25974

Table 8: Class level metrics (PD, LPI and IJI) for PTR of 1987, 2000 and 2020

TYPE	PD			LPI			IJI		
	1987	2000	2020	1987	2000	2020	1987	2000	2020
Dense forest	8.85	7.87	5.67	38.02	34.15	53.49	43.24	31.92	20.28
Open forest	9.32	12.54	15.55	8.49	6.93	7.44	25.97	28.11	24.06
Rocky/ barren	2.94	2.98	3.09	0.12	0.06	0.03	52.84	64.40	70.71
Grassland	6.97	4.63	3.00	0.41	1.15	0.85	61.21	76.31	49.74
Settlement	0.13	0.19	0.26	0.00	0.01	0.01	52.22	67.87	56.63
Water body	0.47	0.22	0.24	1.79	1.59	1.77	49.60	59.47	40.72
Agriculture	0.00	0	0.00	0.00	0	0.00	0	0	27.93
	28.6	28.440	27.812						

Fragmentation analysis is important in order to learn more about the pattern of changes in land cover as well as their extent. How patterns of forest cover vary over time is revealed by the FRAGSTATS analyses of the three individual year using categories of forests and non-forests. Inside PTR, the distribution of forest patches varied substantially between the three years (Tables 7 and 8). Of great interest it is clear that, gradual increase of CA and PLAND (Figure 13 and 14) and decrease of NP (Figure 15) and PD (Figure 16) according to the progression of these three years in the dense forest shows a red signal to fragmentation on this particular class. By 2020 class area reached 579.22 ha from 513.35 ha in 1987 (Table 7). Likewise NP decreased from 8269 (1987) to 5299 (2020) (Table 7). Each class area in the

study region was computed, along with the percentage of the landscape each class takes up and the Largest Patch Index (LPI) value. This class shows highest landscape percentage and it is increasing in a moderate manner (Figure 17), shows that dense forest occupies 54.9457% to 61.9788 % from the year 1987 to 2020, means that it occupies more than half of the total landscape. Even though LPI decrease from 1987 (38.0218%) to 2000 (34.1484%), by 2020 it increased as 53.48%. Here interspersion is decreasing from 43.238% to 20.2821% when considering the years from 1987 to 2020 (Table 7 and 8).

Comparing the results obtained for dense forest, results of open forest are contradictory to an extent. Class area decreased from 1987 (296.83 ha) to 2020 (277.18 ha). Along with that percentage of landscape was also decreasing with increasing of years. Increasing values of NP and PD shows the increasing of fragmentation in open forest from 1987 to 2020. Likewise that of dense forest LPI increases from 2000 (6.9347%) to 2020 (7.4408%). While, IJI increased from 1987 (25.9687%) to 2000 (28.1142%), but then decreased to 24.0591% in 2020. It focus to the point that patch adjacency is decreased, means more fragmented.

In the case of rocky and barren land CA and PLAND is decreasing, means area wise this class show decreasing order from 1987 to 2020. Class area decreased from 22.76 ha in 1987 to 12.09 ha in 2020. The results of NP and PD advocate that fragmentation occurred in this class from 1987 to 2020 in an increasing manner. Adding to this, PLAND and LPI also decreased. Here patch adjacency is increasing from 52.84% (in 1987) to 70.70 % (in 2020). Considering the grassland, there is an increase in CA, PLAND, LPI and IJI till 2000. But from 2000 to 2020, all these four indices show a decrease. While indices viz. NP and PD shows gradual decrease from 1987 to 2020, IJI is increasing in the case of settlements till 2000 and went down when reaches 2020 (Figure 18). Patch adjacency of water body also shows same trend as that in the settlement class. All other indices of water body decrease till 2000, then show an increase to 2020. Agriculture or plantation has very low patch area inside PTR boundary. Meanwhile interspersion of patches was also increasing in these years.

Class Area

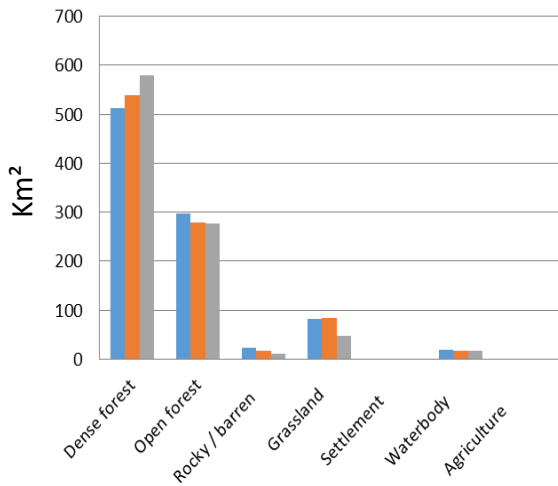


Figure 13: Class area of PTR

Percentage of Landscape

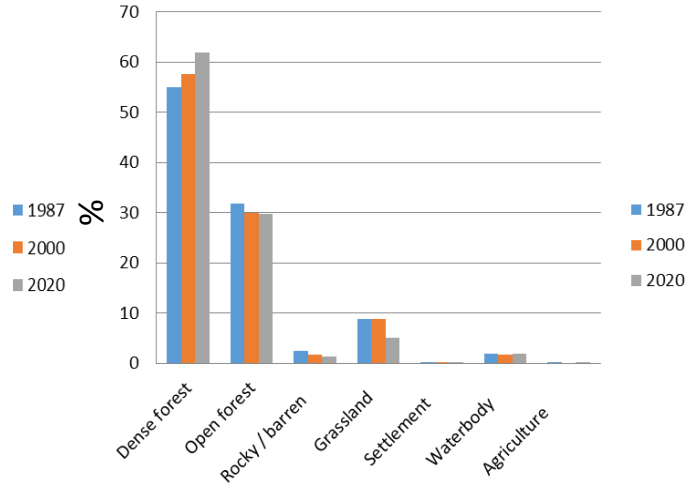


Figure 14: PLAND of PTR

Number of Patches

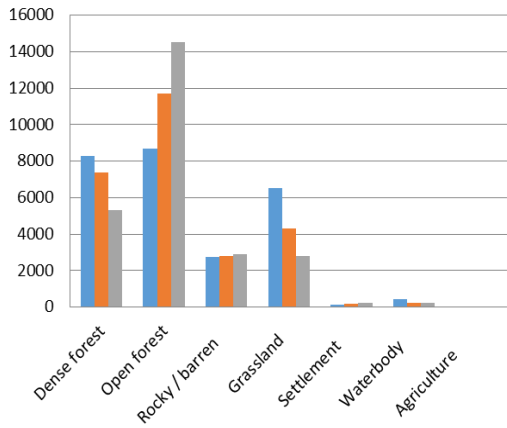


Figure 15: NP of PTR

Patch Density

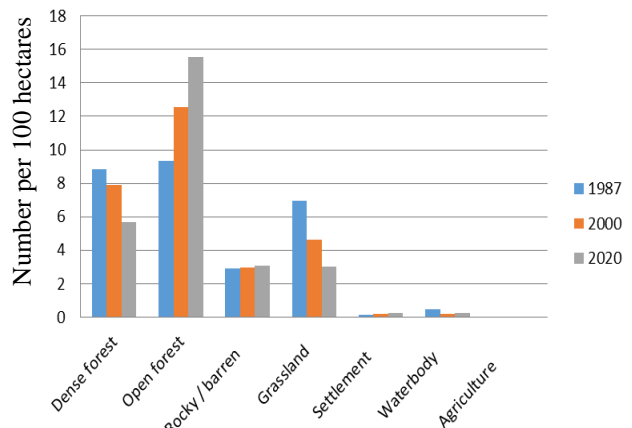


Figure 16: PD of PTR

Largest Patch Index

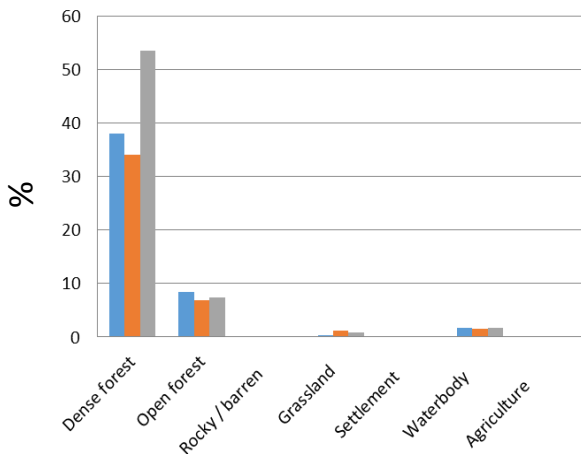


Figure 17: LPI of PTR

Interspersion and Juxtaposition Index

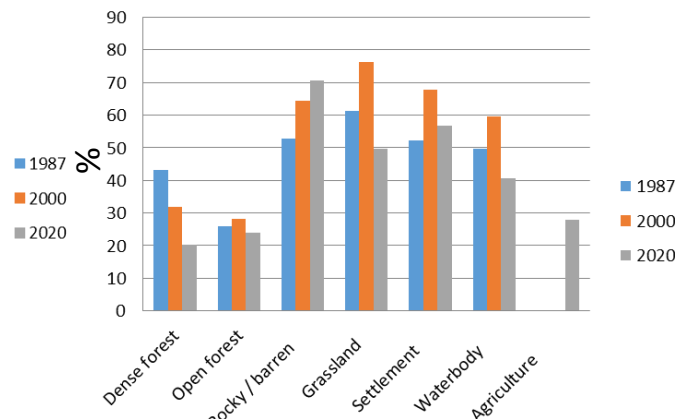


Figure 18: IJI of PTR

Highest class area and PLAND values belongs to dense forest, inside the PTR (Figure 11 and 12). And open forest come next in area wise. Among other class patches grassland occupies the high value. The overall number of forest patches through time shows changes in land use in the study area. NP and PD value of open forest patches surpassed these values in dense forest. Rocky and barren land values of NP and PD stays next to grassland (Figure 13 and 14). Largest patches index is higher to dense forest (Figure 15). Among other class LPI is higher to open forest. Other class values for this index are negligible. IJI of grassland have more equal adjacency to each other classes compared to others. Open forest shows comparatively disproportionate distribution of patch type adjacencies (Figure 16).

Table 9: Landscape indices calculated for PTR

Landscape	1987	2000	2020
TA	934.28	934.28	934.28
NP	26794	26569	25974
PD	28.68	28.44	27.81
LPI	38.02	34.15	53.49
IJI	41.11	40.26	28.20

In landscape level metrics total landscape area (TA) is constant in all three years. While considering total NP in whole the landscape, it shows a gradual decrease from 1987 to 2020 (change of 820 patches). Along with that number of patches per unit area is also decreasing. Comparing the statistical parameters, overall fragmentation is decreasing from 1987 to 2020. But still the interspersions of fragmented patches are increasing (Table 9).

Table 10: Class level metrics (CA, PLAND and NP) for PTR buffer (1km) of 1987, 2000 and 2020

TYPE	CA			PLAND			NP		
	1987	2000	2020	1987	2000	2020	1987	2000	2020
Dense	101.26	107.8	115.26	46.82	49.82	53.32	2757	2779	1898
Open	81.83	80.76	78.84	37.89	37.36	36.47	2768	3182	3275
Rocky/ barren	7.99	3.52	4.06	3.69	1.63	1.87	1160	673	829
Grassland	20.58	16.71	9.79	9.52	7.77	4.54	2047	1798	1292
Settlement	0.54	0.99	1.68	0.255	0.46	0.77	216	350	331
Water body	2.46	1.85	2.03	1.13	0.86	0.92	95	76	74
Agriculture	1.33	2.16	3.32	0.61	1.00	1.54	127	98	111
	216.31	216.31	216.31				9170	8956	7810

Table 11: Class level metrics (PD, LPI and IJI) for PTR buffer (1km) of 1987, 2000 and 2020

TYPE	PD			LPI			IJI		
	1987	2000	2020	1987	2000	2020	1987	2000	2020
Dense	12.77	12.90	8.82	7.80	5.44	8.17	50.20	34.13	31.79
Open	12.82	14.78	15.23	2.16	3.10	4.57	33.96	30.34	33.93
Rocky/ barren	5.37	3.12	3.85	0.42	0.11	0.11	50.13	64.47	78.67
Grassland	9.48	8.35	6.01	0.61	0.35	0.23	56.99	67.66	51.82
Settlement	1.00	1.62	1.54	0.02	0.03	0.28	56.69	66.83	64.99
Water body	0.44	0.35	0.34	0.51	0.37	0.45	37.50	53.60	41.39
Agriculture	0.59	0.45	0.52	0.09	0.18	0.79	38.93	44.44	51.74
	42.48	41.599	36.308						

Showing a similar trend as the area inside PTR the area lies just to the boundary also shows an increase of class area of dense vegetation from 1987 (101.26) to 2020 (115.26) (Table 10). Similar to that percentage of landscape also increased. But the patch adjacency is getting decreased from 50.20% to 31.78%. NP and PD increased till 2000 then show a fall from 2000 to 2020. In the selected buffer grassland is decreasing in its area and number of patches. Rocky and barren class show a decrease till 2000 but then increased. Settlement and agriculture classes shows rise in area wise. Also their percentage of landscape is increasing. Patch adjacency of agriculture land is increasing from 1987 to 2020 (Table 11).

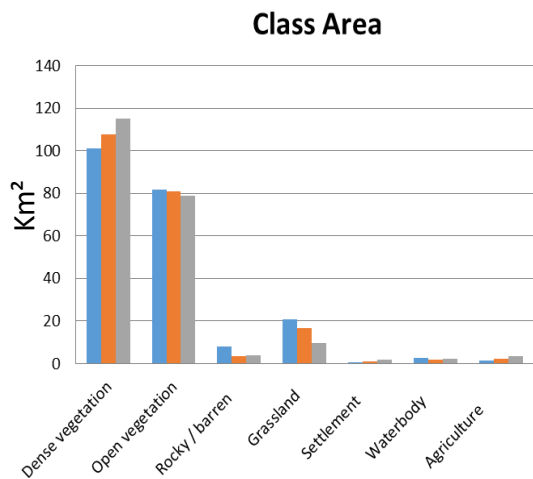


Figure 19: Class area of PTR buffer

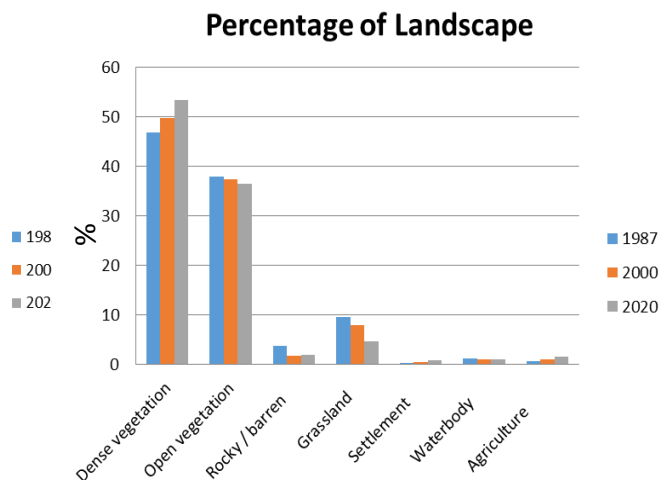


Figure 20: PLAND of PTR buffer

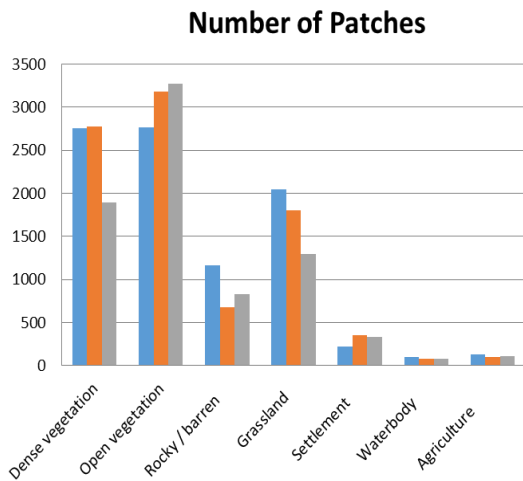


Figure 21: NP of PTR buffer

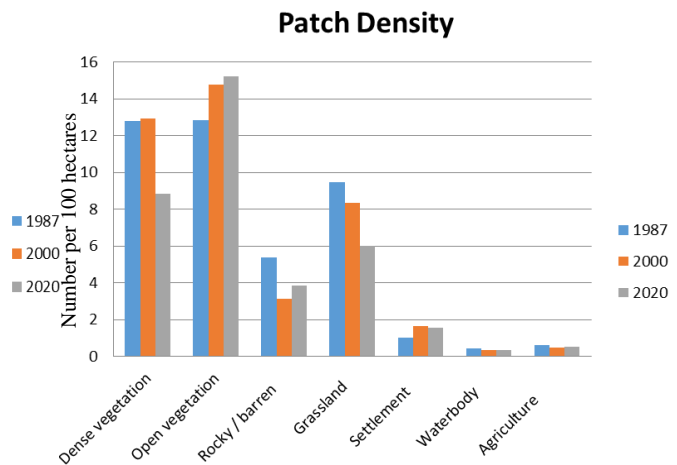


Figure 22: PD of PTR buffer

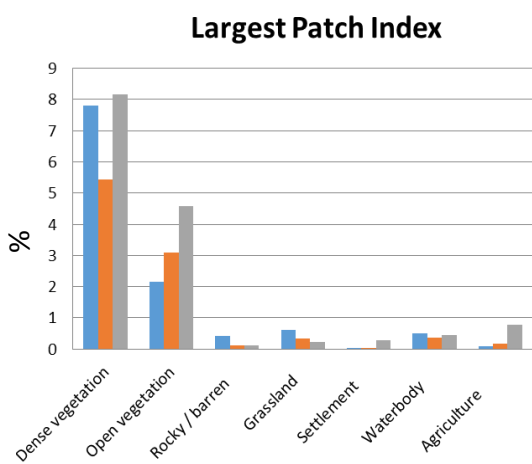


Figure 23: LPI of PTR buffer

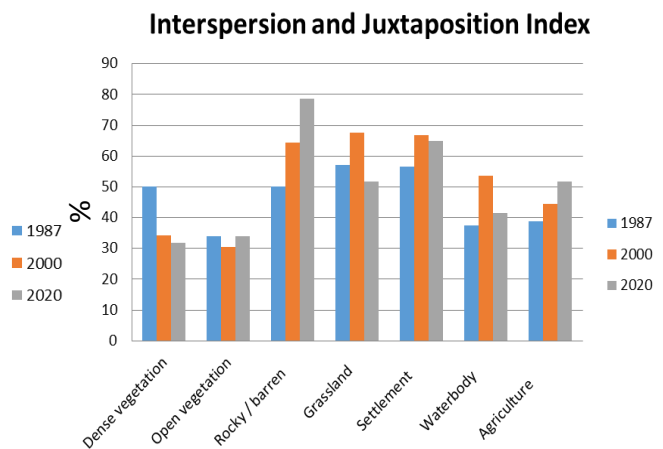


Figure 24: IJI of PTR buffer

Similar to the area inside PTR, the selected buffer of 1 km also shows higher CA and PLAND to dense vegetation (Figure 19 and 20). Even though NP and PD are high for open vegetation, the difference of these indices between open and dense vegetation is negligible. Grassland values are also closer to the dense vegetation values in the case of NP and PD (Figure 21 and 22). The largest patch coverage computed using the FRAGSTATS show high values to dense and open vegetation cover. Values of LPI for other classes are lesser (Figure 23). Rock or barren land patches are more equally adjacent to all other patch types than others (Figure 24). Except dense and open vegetation other classes have comparatively higher values.

Table 12: Landscape level metrics for PTR buffer (1km) in 1987-2000-2020

Landscape	1987	2000	2020
TA	216.31	216.31	216.31
NP	9170	8956	7810
PD	42.48	41.60	36.31
LPI	7.80	5.44	8.17
IJI	46.14	39.84	39.73

Considering the total landscape buffer area of 216.31 km², NP and PD is decreasing steadily. Patch adjacency also getting reduced (Table 12).

4.5 MANN-WHITNEY TEST – INSIDE PTR

The data generated by the FRAGSTATS were evaluated using Mann-Whitney testing. Test is applied to the patch area, because it is the only index having equal total value. Balance indices are fluctuating highly in its total value. Mann-Whitney test results showed differences in patch area ($p < 0.05$) as tabulated in (Table 13).

Table 13: Patch area compared by Mann-Whitney Tests in PTR

Class	Z-value	Prob > z 	Z-value	Prob > z
	(1987-2000)		(2000-2020)	
Water body	32282	0	21968	0.17
Dense forest	24483206	0	15803286	0
Open forest	44833980	0	66451040	0
Rocky/ Barren	3141041	0	3582763	0
Settlement	7262	0	16289	0
Grassland	10934557	0	5359566	0

These findings served as a reliable sign of rapidly changing landscape. Here values of water body from 2000 to 2020 didn't show a significant variation. Except that all other values are varying significantly.

4.6 FOREST CLASSIFICATION

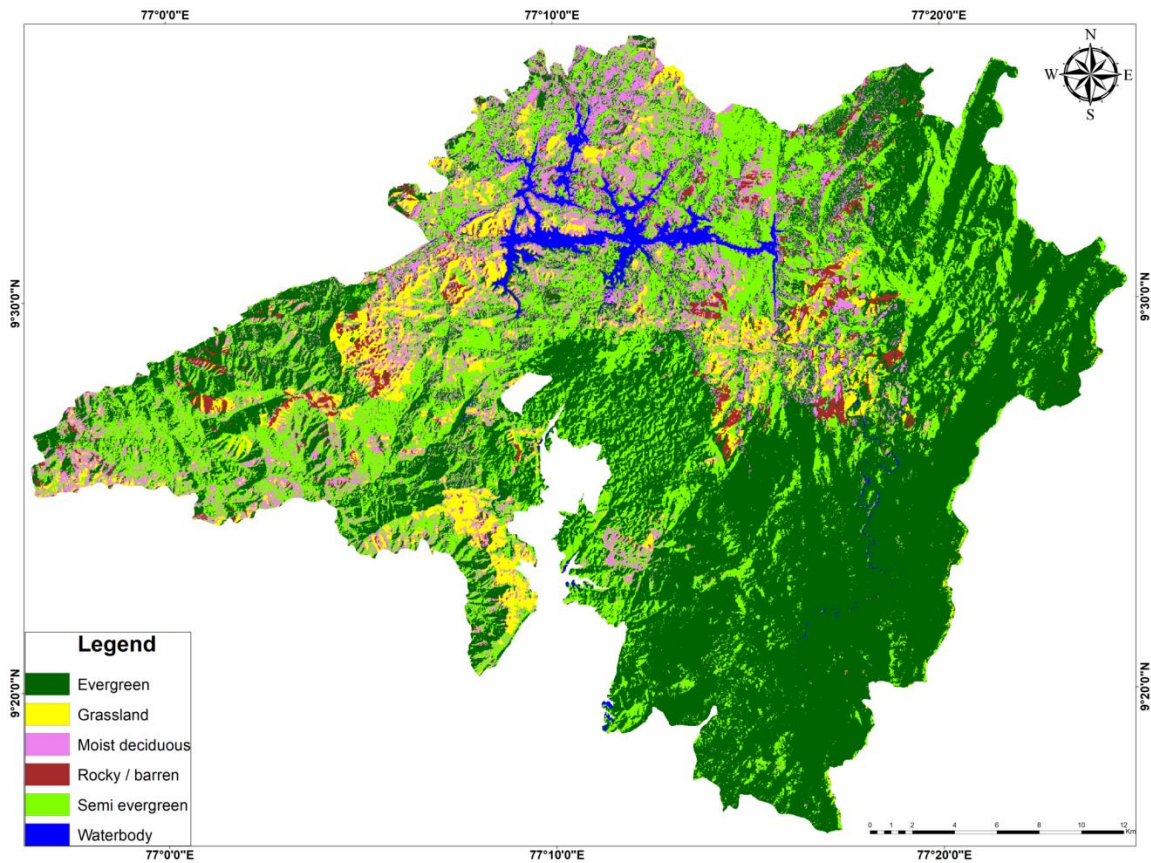


Figure 25: Map of forest type classification of PTR (inside) in 1987

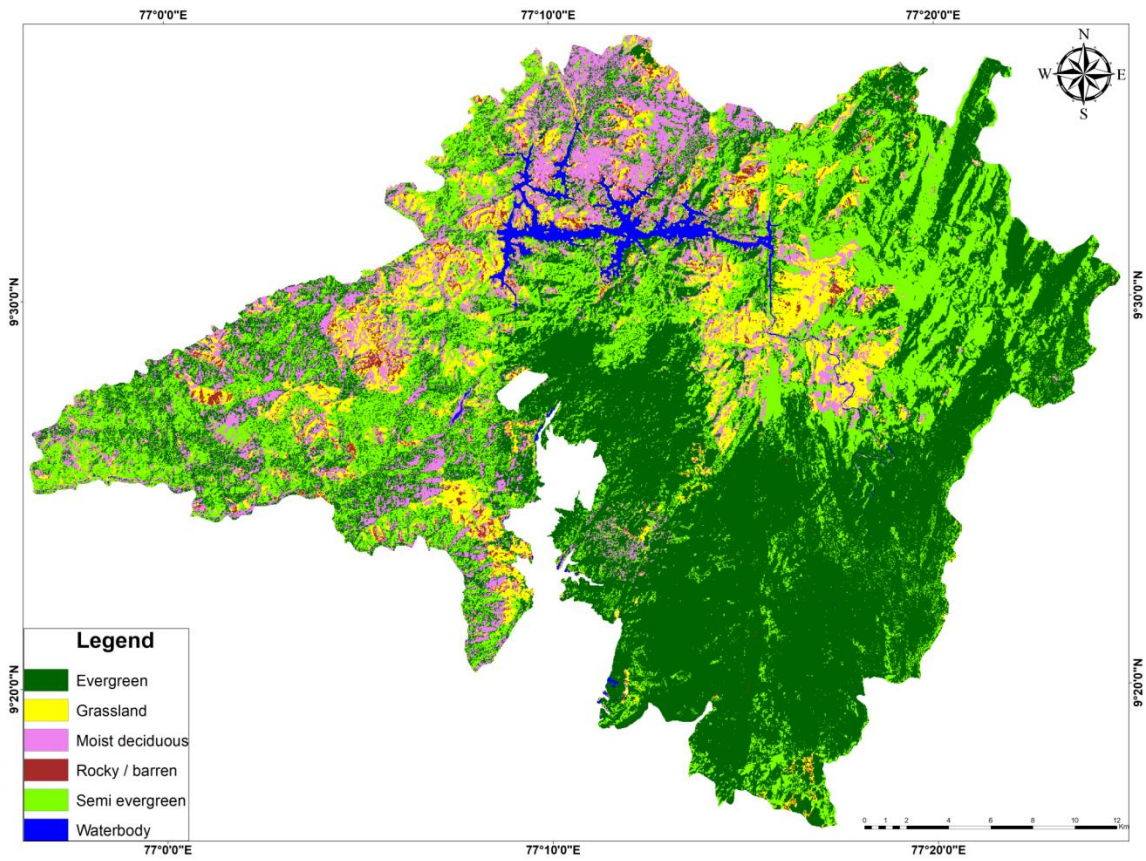


Figure 26: Map of forest type classification of PTR (inside) in 2000

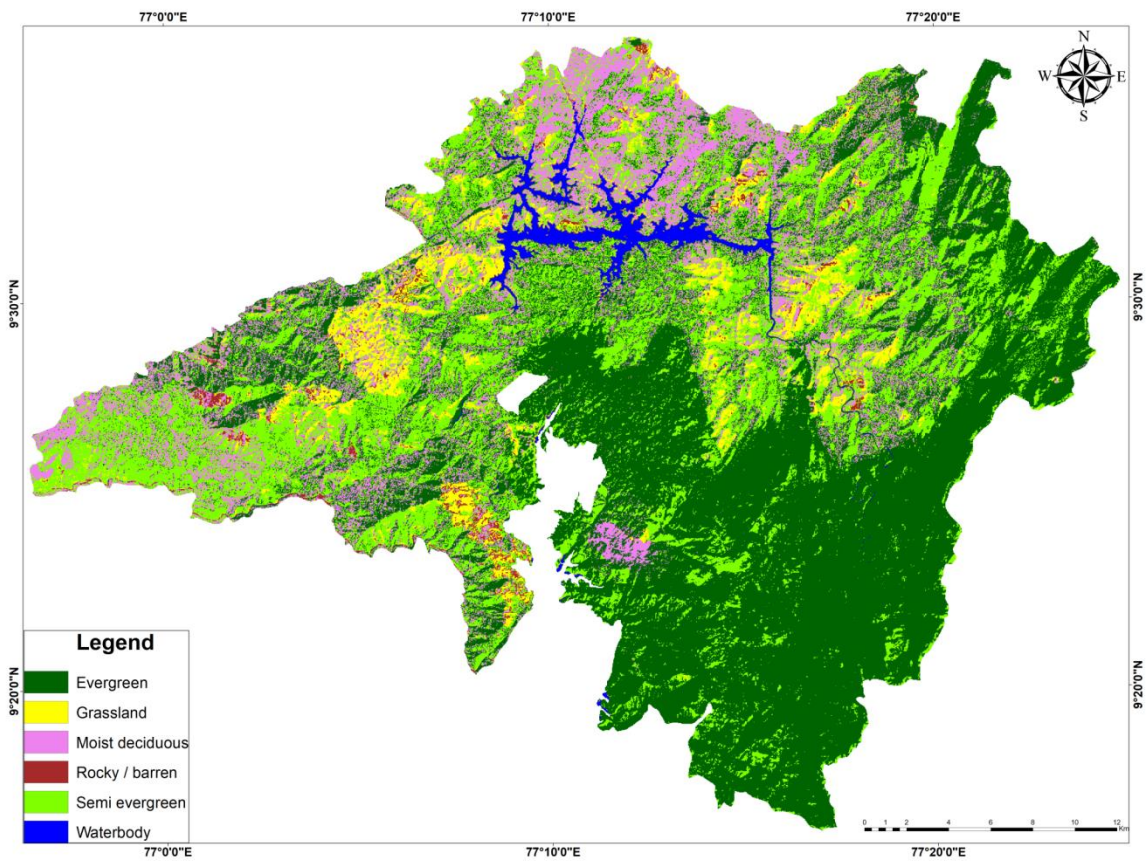


Figure 27: Map of forest type classification of PTR (inside) in 2020

Table 14: Area of forest type classes of PTR (inside) for the year 1987, 2000 and 2020

Forest	1987 (km ²)	%	2000 (km ²)	%	2020 (km ²)	%
Water body	18.54	1.98	16.35	1.75	17.33	1.86
Evergreen	456.46	49.93	450.78	48.25	438.11	46.91
Moist deciduous	116.93	12.52	111.28	11.91	141.07	15.11
Semi evergreen	237.14	27.48	255.96	27.34	278.08	29.7
Rocky / barren	22.76	2.44	16.47	1.76	12.09	1.29
Grassland	82.45	8.82	83.39	8.93	47.6	5.1
Total	934.28	103.17	934.28	100	934.28	100

Table 15: Difference in area of classes under forest classification during 1987, 2000 and 2020

Forest Classification	1987-2000 (km ²)	2000-2020 (km ²)	1987-2020 (km ²)
Water body	-2.19	0.98	-1.21
Evergreen	-5.68	-12.67	-18.35
Moist deciduous	-5.65	29.79	24.14
Semi evergreen	18.82	22.12	40.94
Rocky / barren	-6.29	-4.38	-10.67
Grassland	0.94	-35.79	-34.85

Other than that of the water body, rocky or barren land and grass land which was already mentioned earlier, in this classification more importance is given to the evergreen, moist deciduous and semi evergreen classes. Evergreen patches show a decrease of 5.68 km² (Table 15) from 49.93% (Table 14) in 1987 (Figure 25) to 48.25% in 2000 (Figure 26). Here there is a loss of 12.67 km² when comparing 2000 and 2020 (Figure 27). In total from 1987 to 2020, 18.35 km² of evergreen forest area has changed to some other land use classes. Even though moist deciduous forest area decreased from 1987 (12.52%) to 2000 (11.91%) and increased from 2000 to 2020 (15.11%), it shows a total of 24.14 km² area progress when we check results from 1987 to 2020. Semi evergreen forest type shows a gradual increase in its

area. 25.38% in 1987 reaches 29.70% in 2020 and have a positive rise of 40.94 km² in total (Table 15).

Table 16: Accuracy assessment of forest type classification map of 2020

Class No.	Land cover classes	Producer's accuracy (%)	User's accuracy (%)
1	Water body	100	100
2	Evergreen	75	100
3	Semi-evergreen	71.42	83.3
4	Moist deciduous	100	71.42
5	Grass land	71.42	71.42
6	Rocky/ barren	83.33	71.42

The obtained kappa coefficient for the map of 2020 forest classification is 0.78 and overall accuracy is 82.05% (Table 16).

4.7 CHANGE DETECTION OF FOREST TYPE CLASSES OF THE STUDY AREA BETWEEN 2000 AND 2020

To have a deeper understanding of the changes that happened during a 20-year period, the definition of class changes obtained from satellite images of our study region for the years 2000 and 2020 and their aerial extent are also presented in Figure 28. The statistics table which shows change detection matrix list of forest type classes of 2000 image in the rows and land cover classes of 2020 image in the columns (Table 17). Even though 72.56 km² of semi evergreen class added to evergreen forest type between 2000 and 2020, 64.72 km² and 49.92 km² of evergreen forest type was converted to semi-evergreen and moist deciduous classes respectively cause mainly for the reduction of 12.67 km² of evergreen forest type. At the same time 31.02 km² and 12.67 km² of grassland was converted to semi-evergreen and moist deciduous classes respectively and grassland have a reduction of 35.79 km² of its area. Also 33.85 km² of moist deciduous class get converted to semi evergreen forest type (Table 17).

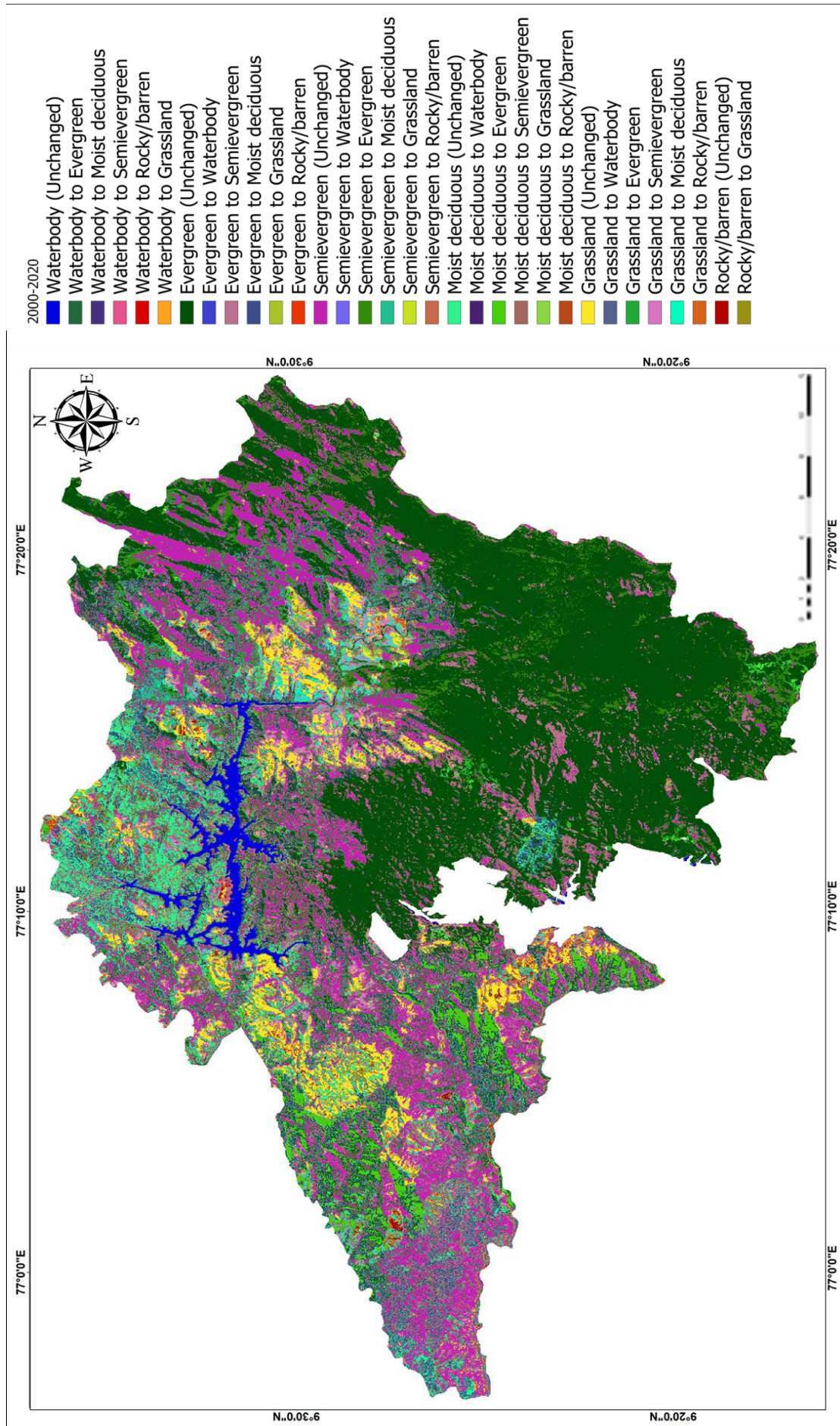


Figure 28: Change detection map of forest type classification between different classes of 2000 and 2020

Table 17: LULCC matrix of forest type classification between the years 2000 and 2020

LULCC		Forest type class – 2020 (km ²)						Grand total
		Evergreen	Grassland	Moist deciduous	Rocky / barren	Semi evergreen	Water body	
Forest type class – 2000 (km ²)	Evergreen	332.88	1.37	49.92	0.64	64.72	1.19	450.78
	Grassland	6.63	31.03	12.67	0.43	31.02	1.71	83.39
	Moist deciduous	25.06	5.4	46.37	0.26	33.85	0.75	111.28
	Rocky / barren	0	6.28	0.16	9.34	0.12	0.3	16.47
	Semi evergreen	72.56	3.4	31.19	0.74	147.89	0.14	255.96
	Water body	1.06	0.12	0.76	0.68	0.44	13.29	16.35
Grand total		438.11	47.6	141.07	12.09	278.08	17.33	934.28

DISCUSSION



DISCUSSION

5.1 CONSERVATIONAL ASPECTS IN PTR

The Green India Mission advocated tree planting as part of the 2008 National Action Plan on Climate Change in order to cover one-third of land area of the country (Rosencranz and Lele, 2008). India's dedication to the 2020 Aichi Biodiversity objective in the 'Strategic Plan for Biodiversity 2011–2020 and the Aichi Targets', i. e., by 2020, degradation and fragmentation will have greatly decreased, and the rate of loss of all natural ecosystems, including forests, will have been at least halved and, where possible, brought down to zero, have also motorised the conservational efforts to a great extent across all the protected areas in the country, especially in PTR. In addition, since 1996, the Supreme Court of India has prohibited all forms of clear-felling in India's forests, leading to severe conservation measures and community forest management (Rosencranz and Lele, 2008). Periyar wildlife sanctuary declaration of 777 km² in 1950, Periyar national park declaration of 350 km² in 1982, Periyar tiger reserve declaration in 1978 and the allocation of buffer and core in 2007 embellished conservation efforts in a better way. Along with that, as per Section 38 V (3), Legal provisions in the Wild Life (Protection) Act, 1972 regarding Tiger Conservation Plan and all other policy level implementation in PTR also promote the more desirable development in PTR. The positive development of the dense forest area in PTR has a great support of all these factors.

5.2 FRAGMENTATION ANALYSIS OF DENSE FOREST INSIDE PTR

As noted, there was a general improvement in the portion of the protected area covered by dense forest habitat. Along with that, the increase in percentage of landscape, reduction in patch density and all other indices calculated viz., LPI and IJI advocate that dense forest inside PTR shows progressive change along these years with a considerable decrease in fragmentation. From the obtained results it can also be assumed that the betterment of dense forest happened after 2000. The percentage of the overall landscape area occupied by the largest patch of dense forest shows an increase in time period from 2000 to 2020. Conservational efforts and proper implementation of management plans during these time period enhance the dense forest by preventing fragmentation. Many plantations were there in the PTR during its beginning time period. Later conversion of these also catalysed the up gradation of this forest class. According to Tiger Conservation Plan (Sukla, 2012), three cardamom estates were located inside the core at the time of PTR's establishment in

1978. In 1984, control of these properties was gained by PTR, and forests were allowed to regenerate. The eucalyptus trees that were planted previously under Grassland Afforestation Division (GLAD) on a 55 km² area failed in large parts. Slowly, the natural forests are returning to these locations (Sukla, 2012). These are few among such conversions. Thus anthropogenic disturbances are reduced for plantation management and the PTR forest authorities prioritise the preservation of natural vegetation (Sundarapandian and Karoor, 2013). Law and policies formulated during these time period also support the decrease in fragmentation. One of the primary goals of the National Forest Policy (NFP), launched in 1988, is to significantly increase the country's forest/tree cover through extensive afforestation and social forestry programmes, particularly on all denuded, degraded, and unproductive lands, and to provide better support to conservational efforts.

FRAGMENTATION ANALYSIS OF OTHER CLASSES INSIDE PTR

Withal the dense forest showed a positive rise, the case of open forest is a bit controversial. Open forest shows a greater dimension of reduction in area along with the occurrence of fragmentation. But a remarkable variation is only from 1987 to 2000, after it the change is negligible. Earlier mentioned conservation measures enhanced open forest also from 2000 to 2020. Along with that the change of plantations to natural forest, may cause to the reduction of open forest area during the 1987 to 2000. Because in the 1:50,000 scale with 30 m resolution satellite images it is hard to distinguish between the small plantations (especially cardamom plantation) with open forest. Here in the case of open forest patches, class area is decreasing and number of patch is increasing. This shows the fragmentation occurring in the open forest patches. The condition of rocky/ barren land is similar to this. But the interspersion is increasing. It shows that fragmented patches have comparatively similar patch adjacency. One thing to notice here is that, in this class along with the rocky patches barren land is also there. When year progress, many of the barren land is get converting to the settlement class of this study. This is main reason to the decrease area of this class.

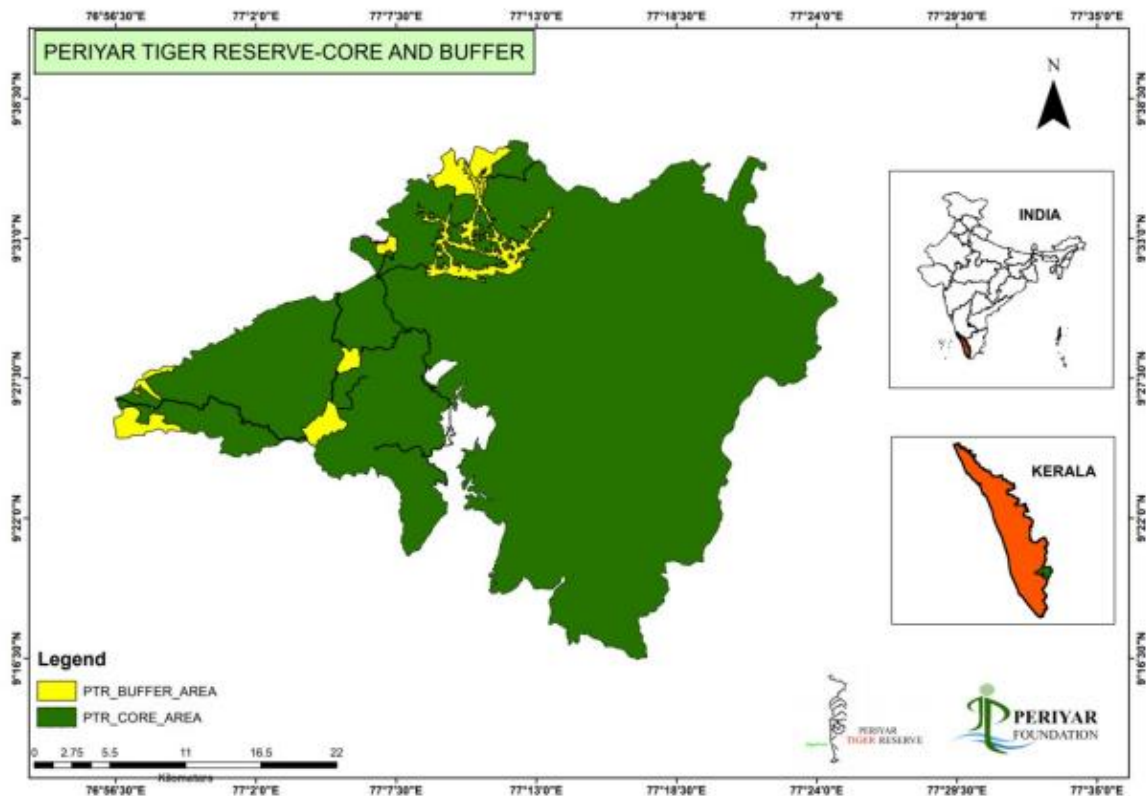


Plate 3: PTR - administrative buffer and core zone map (TCP, 2012)

In the case of PTR, administratively they have buffer and core (Plate 3) inside the selected boundary for this study (Figure 1). Earlier mentioned small conversions of barren land to settlement happened inside such buffers, howbeit, this will reflect in the results of the study. The tourism, pilgrimage, nature education and interpretation facilities are strictly confined to delineated buffer zone of Periyar Tiger Reserve. Due to rising pilgrimage and the Travancore Devaswom Board's (TDB) increasing requests for more lands for the infrastructure development of Sabarimala, the ecology around Sabarimala in this buffer of PTR (Plate 3) is constantly under threat and habitat degradation is having a severe impact (Sukla, 2012). Although protected areas are the focal point of conservation efforts, habitat loss and fragmentation can also occur outside of protected areas also, because of the changes in land use patterns. This will have impact on the complete ecosystem process within protected areas and in its fringe area (Hansen and Defries, 2007). The influence on habitat structure and faunal variety can be used to the better understand of the effects of habitat change and fragmentation in such areas. In addition to creating unhealthy vegetation, human activities have changed the structure and functioning of ecosystems, leading to altered nutrient cycling, altered fire regimes, and other ecological effects (Vitousek *et al.*, 1997).

In the case of grassland, it shows a significant reduction of area in the second half (2000 – 2020) of the study but the level of fragmentation is comparatively less. Even though indices vary between 1987 and 2020, the variation is negligible. Extreme weather can have an immediate and severe impact that alters both human societies and ecosystems. Influence of extreme weather situations can have a robust influence in the conversion of grassland to other classes. Hermann *et al.*, (2016) found that regardless of protection status, the effective conservation risk was often greater for grassland than for forest. Grassland, which is one of the important biome, has a great influence in the food cycle of many of the wild fauna. As a result of destruction of grasslands, the composition of the flora will change, species variety will decrease, and the amount of wildlife will decrease (Adane *et al.*, 2018).

The number of patches is an effective index of fragmentation. If the area of the landscape is constant, more patches describe more fragmentation. Apart from dense forest area, all other classes show more or less fragmentation inside PTR. It is solidly proved that efficient forest management made the forest denser. The decrease of barren area inside PTR shows the increase of this area in other classes especially in to dense patches, because area wise this particular class shows the better increment. Even though the increase of dense forest and forest management is good, fragmentation occurring in other classes is not as such positive matter to discuss. Some factors enhance the fragmentation of classes other than dense forest. Protected area-wise, decadal analysis indicates that Periyar have high number of forest fire incidences (Athira *et al.*, 2017). According to Ajin *et al.*, (2016) 31 forest fires occurred during the years from 2004 to 2014, shows that PTR is prone to forest fire. These extreme fire incidents can also influence to the fragmentation of the patches like open forest and grassland. At the same time Kerala received significantly high Indian summer monsoon rainfall (ISMR) from 1 June 2018 to 19 August 2018 (on an average of 2346.6 mm), that is around 42% more rain than would normally occur during the same time frame. Among the various districts of Kerala, Idukki which incorporates PTR has received the maximum amount of rainfall, which was over 100% more compared to the normal rainfall (3555 mm rainfall to the normal 1852 mm). Along with that raising water level at the dam for the distribution of water looks like an attempt to disregard many of the elementary conditions of ecological security (Anon., 2007). These reasons can contribute to the increase in the water body from 2000 to 2020.

5.3 FRAGMENTATION ANALYSIS OF SELECTED 1 KM BUFFER OUTSIDE PTR

Whilst the land use pattern of selected buffer of 1 km shows the influence of forest in buffer and buffer in forest. Dense vegetation patch in buffer shows an increase in its area and comparatively decreased fragmentation, similar to that of dense forest. But here in the buffer, dense vegetation show a fragmentation up to middle of the study period, but gradually it got decreased. Open vegetation is getting more fragmented. But in the case of grassland, it is totally decreasing. Grazing and land conversions can be the main reason to this area wise reduction. Barren land is more equally interspersed compared to other classes in buffer region. Settlement and grass land come next to the patch adjacency. According to this study constructions and agriculture is increasing outside boundary of PTR. Comparing to the protected area, more development was happening outside along with the progress in fragmentation. Similar studies are there which explain the increased fragmentation outside the protected areas (Srinivasan *et al.*, 2022). Such human induced fragmentations can induce pressure to the forest and its structure. One other fact to be notice is that, for a protected area increase of dense forest is an admirable fact of forest management and positive ecological factors. But while checking the area just to the selected buffer of study (Figure 5, 6 and 7) and PTR buffer (Plate 3) we can observe the presence of open forest (Figure 5, 6 and 7). It point out to the reality of the negative effects of buffer. According to Sundarapandian and Karoor (2013), in PTR, high species richness and diversity has observed in the undisturbed forest compared to forest area adjacent to the villages or human settlements. The trend followed in these years disclose that buffer areas are likely most at risk for land conversion in the future. And apparently this will affect the fringe forest area which finally leads to core forest. Many studies point out that the buffer zones and areas outside of protected areas are often highly degraded, and that this degradation can have significant impacts on the ecological integrity of the protected area itself. Greater efforts are needed to address threats to these areas and to better integrate protected areas into broader landscape-scale conservation strategies (Watson *et al.*, 2018). According to Ewers and Bank (2013), the species that live in tropical forests are among those that are most vulnerable to climate change, the forest that they are surrounded by acts as a buffer between the microclimate inside and the changing environment outside. The ability of the forest to absorb climatic fluctuation is, however, diminished by habitat fragmentation and edge effects, which expose vegetation to external microclimate conditions.

5.4 ANALYSIS OF FOREST CLASSIFICATION

In congruence with the obtained findings, the decrease in evergreen forest patch can be observed in these years inside PTR. Along with that we can observe an increase in the moist deciduous forest type after the year 2000. However semi evergreen forest has a gradual increase from 2000 to 2020. Various internal disturbances and ecological factors have been contributed to the change in forest type. From the change matrix analysis, we can get to know that the fact behind the reduction of evergreen forest class is mainly due to the conversion of evergreen patch to semi-evergreen and moist deciduous forest types. Along with that, the reduction in the area of grassland also advocate the conversion of the same classes (semi-evergreen and moist deciduous) from grassland forest type. At the same time the apparent increase of semi evergreen forest type was also contributed by the area conversion from moist deciduous patches also.

5.5 FUTURE LINE OF WORK

The study of forest fragmentation analysis is quite relevant in the current decade. Comparing decadal change in land cover, along with fragmentation analysis pave a better way for forest management. Studies merging forest canopy density monitoring with this line of study can enhance the assessment of fragmenting vegetation. Researches concentrating in the in the analysis of largest patches in the forest vegetation can help to determine the behavioural pattern of fragmentation along the decades. Modelling studies in the title of land use fragmentation also gain much importance during these days.

Here in this study along with checking of the rate of fragmentation, characteristics of fragments are also analysed. By conducting decadal analysis of fragmentation studies in protected areas and in its buffers can augment the credibility of selecting a particular size for buffers. Also such investigations can report need of buffers around the protected areas.

SUMMARY



SUMMARY

The main objectives of the study entitled as “Landscape fragmentation analysis using geospatial tools in Periyar Tiger Reserve, Kerala” are, evaluation of forest fragmentation inside and in the selected 1km buffer around PTR and analyzing the land use land cover change in the study region for the years 1987, 2000 and 2020. The comparison of NDVI for 2000 and 2020 was also done. The results obtained from the study are summarized below:

1. According to the data obtained from NDVI, 0.53, the high value obtained in NDVI 2000 get increased to 0.61 in 2020. For the NDVI 2000, obtained mean value is 0.31 and standard deviation is 0.06. Mean value obtained for 2020 NDVI is 0.33 standard deviation is 0.08.
2. Inside the PTR, LULC map shows a significant increase in the overall area of dense forest which is 65.87 km² from 1987 to 2020.
3. A total of 19.65 km² and 10.67 km² of open forest and rocky or barren land respectively have decreased from 1987 to 2020.
4. In the case of grassland an overall of 34.85 km² has decreased from 1987 to 2020.
5. Land modification occurred in the settlement category shows a slight increment of 0.51 km² area and there is no remarkable area of agriculture land use. From 2000 to 2020 water body shows showed an increase of 0.98 km² area.
6. The obtained kappa coefficient for the LULC map of 2020 is 0.84 and overall accuracy is 86.36%.
7. In the 1 km buffer taken around PTR an area of 216.31 km² was classified.
8. Likewise, the trend inside the PTR boundary, a consistent increase of area under dense vegetation (14 km² from 1987 to 2020) was there in the selected buffer area also.
9. An optimal decrease in the land area of open vegetation and grassland show the similarity of buffer to the study area.
10. Opposite to the land use trend inside the PTR boundary, the agriculture and settlement classes in the selected buffer area show the substantial land modifications along with the increment in area.
11. These results obtained from Mann-Whitney tests was a strong indicator of a rapidly changing landscape. Here values of water body from 2000 to 2020 didn't show a

significant variation. Except that all other class patches have significant change in area.

12. Fragmentation analysis from the FRAGSTAT software proved that the pattern of forest patches inside PTR varied significantly across all the three years.
13. Dense forest which occupies the largest patch area inside PTR has increase of CA and PLAND along with the decrease of NP and PD shows the decreased fragmentation inside PTR.
14. In dense forest class LPI decrease from 1987 (38.0218%) to 2000 (34.1484%), but by 2020 it increased as 53.48%. Here interspersion is decreasing from 43.238% to 20.2821% when considering the years from 1987 to 2020.
15. The results obtained for open forest shows a decrease of CA and PLAND and increase in NP and PD shows the increasing of fragmentation in open forest from 1987 to 2020.
16. In the case of rocky and barren land also CA, PLAND and LPI are decreasing, and NP and PD are increasing. Here patch adjacency is increasing.
17. In grassland class, there is an increase in CA, PLAND, LPI and IJI till 2000. But from 2000 to 2020, all these four indices show a decrease. While indices viz. NP and PD shows gradual decrease from 1987 to 2020.
18. IJI is increasing in the case of settlements till 2000 and went down when reaches 2020. Patch adjacency of water body also shows same trend as that in the settlement class. All other indices of water body decrease till 2000, then show an increase to 2020. Agriculture or plantation has very low patch area inside PTR boundary. Meanwhile interspersion of patches was also increasing in these years.
19. Highest class area and PLAND values belongs to dense forest, inside the PTR. NP and PD value of open forest patches surpassed these values in dense forest. IJI of grassland have more equal adjacency to each other classes compared to others classes.
20. Total NP in complete landscape shows a gradual decrease from 1987 to 2020 (change of 820 patches).
21. In 1 km buffer dense forest show less fragmentation. Settlement and agriculture in increasing in its percentage of landscape.
22. Higher CA, LPI and PLAND values are with dense vegetation. Open forest have highest number of patches per unit area. Rocky or barren land shows highest patch adjacency.

23. From the forest classification, evergreen patches show a decrease of 18.35 km² from 1987 to 2020. Moist deciduous forest has a total of 24.14 km² area increment and semi evergreen forest type have a positive rise of 40.94 km² in total area from 1987 to 2020.
24. The obtained kappa coefficient for the map of 2020 forest classification is 0.78 and overall accuracy is 82.05%.
25. Between 2000 and 2020, 64.72 km² and 49.92 km² of evergreen forest type was converted to semi-evergreen and moist deciduous classes respectively. At the same time 31.02 km² and 12.67 km² of grassland was converted to semi-evergreen and moist deciduous classes respectively. Also 33.85 km² of moist deciduous class get converted to semi evergreen forest type.

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Landscape fragmentation analysis using geospatial tools in Periyar Tiger Reserve, Kerala

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ABSTRACT

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ABSTRACT

Periyar Tiger Reserve (PTR) is one of the largest conservation units in Western Ghats and many conservational efforts are formulated and applied in this area. It is also important to monitor the outcome of these efforts to strategize further management techniques. Geoinformatics approach widely used to monitor land use change as well as forest fragmentation, as the satellite data are easily accessible and they are more consistent in assessing global forest change (Hansen *et al.*, 2013, Carranza *et al.*, 2014, Srinivasan *et al.*, 2022). This study compared the fragmentation status of forest habitats of PTR in 1987, 2000 and 2020 by analysing the landscape level and class level conservation measures by employing remote sensing-based datasets on forest cover and fragmentation. The FRAGSTATS software analysis along with the LULC (Land Use Land Cover) classification and NDVI (Normalised difference vegetation Index) analysis of the forest/non-forest classifications for each of the three distinct years revealed the pattern of forest cover change over time. Image frames were compared for each year for PTR and a one km buffer around PTR boundary showed a considerable variation in the forest patch pattern.

The results revealed that dense forest patches within PTR had a favourable increase in the area combined with a decrease in fragmentation. The increase in the largest patch index of the dense forest in 2020 showed the positive effect of the declarations, policies and other conservation measures implemented in this area. Comparative increment in NDVI values over the years, 2000 and 2020 indicated a steady increase of healthy vegetation. The prevalence of agriculture and habitation haven't increased noticeably in this study area, despite the fact that open forest, grassland, and rocky and barren terrain exhibit fragmentation during this particular study period. The meagre construction works inside the administrative buffer of PTR and the expansion of dense forest can vote for the decrease of barren land and grassland counted in this study. A slight increase of open patches and an increase of semi-evergreen and moist deciduous patches near the forest adjacent to the buffers showed minor negative effects of buffer on adjacent forest. At the same time a similar trend was observed while comparing PTR with buffer. In fragmentation analysis, buffer also showed decreased fragmentation in the dense vegetation patch after 2000 but here a proportional increase of agriculture and settlement was observed.

The findings indicated that this tiger reserve area is very dynamic. After the declaration, efficient conservation measures and eco-friendly regulations showed positive results and has been successful in preventing forest fragmentation. The improvement of protected areas like PTR depends on conservation strategies for its ecological development. The baseline data from this study can be used to prioritise conservation efforts of Periyar Tiger Reserve in Western Ghats. The study also recommends PTR model of conservation to be further extended to other protected areas with local adaptations and modifications.