



ANALYSIS OF LONG-TERM SPATIO-TEMPORAL TRENDS IN LAND USE/LAND COVER IN DEVIKULAM TALUK, KERALA USING GEOSPATIAL TECHNIQUES

Srishti Solanki^{ID*}, Chindu Chandran^{ID}, J.K. Garg^{ID} and Prodyut Bhattacharya^{ID}

University School of Environment Management, Guru Gobind Singh Indraprastha University, Sector- 16C,
Dwarka, New Delhi - 110075, India

*Corresponding author: srishtisolanki01@gmail.com

Abstract

This study was undertaken to evaluate the spatial as well as the temporal changes in land use/ land cover in Devikulam Taluk, Idukki District, Kerala, and to assess the effects of increasing anthropogenic pressure on the fragile ecosystem of this area. For analysis, land use/ land cover maps of four different years, i.e., 1988, 1999, 2008 and 2017, were generated using LANDSAT TM (Thematic Mapper), ETM+ (Enhanced Thematic Mapper Plus) and OLI/TIRS (Operational Land Imager/Thermal InfraRed Sensor) satellite imagery. The results of the study suggested that there has been a drastic increase in the built-up area and a continuous decline in the forest area in Devikulam from 35.31 km² built-up in 1988 to 73.92 km² in 2017, and 1374.52 km² forest in 1988 to 1247.24 km² in 2017, respectively. Over this period of approximately 40 years, around 47.85 km² area of the forest got converted to built-up. This could be due to the increasing anthropogenic pressure in terms of migration or booming tourism contributing to the increased demand for infrastructures. Therefore, appropriate land use planning is a fundamental step towards the sustainable development of this biogeographically rich and unique area of Devikulam Taluk.

Keywords: Change Detection, Devikulam Taluk, Land Use and Land Cover, LANDSAT imagery, Remote Sensing and GIS

DOI: <http://dx.doi.org/10.3126/ije.v8i3.26616>

Copyright ©2019 IJE

This work is licensed under a CC BY-NC which permits use, distribution and reproduction in any medium provided the original work is properly cited and is not for commercial purposes

Introduction

The Western Ghats, a mountain range of 1,40,000 km² area running parallel to the western coast of the Indian Peninsula, India, is a recognized world biodiversity hotspot, known for their vast variety of biological diversity and its conservation. Devikulam Taluk, Kerala, is a good representative of its biological and geological diversity, located in the Western Ghats. Devikulam, spread over 1800 km² of area, harbours many protected areas (Binutha and Somashekar, 2014). In the past few years, the Western Ghats suffered rapid deforestation and degradation because of huge scale transformation of forest land for fuelwood, roads, tea and coffee estates, rapid infrastructure development, etc., which has serious ramifications affecting the biodiversity of the region (Kale, 2016). The booming tourism also contributes to the increased demand for infrastructure and rapid urban expansion in a short period (Mani, 2012). This is an unsustainable approach to land management (Jha *et al.*, 2000; Kumar, 2005; Binutha and Somashekar, 2014).

The processes of land use and land cover (LULC) changes occurring on the earth's surface are ever-changing and progressive. These changes taking place on the surface, both spatial and temporal, play a major role in various fields, e.g., natural resource management, biodiversity studies, etc. LULC mapping serves as a basic land resource inventory tool worldwide. Remote sensing serves as a medium for acquiring LULC data and delivering efficient and well-timed products, be it regional or local. Lately, remote sensing and Geographical Information System (GIS) have gained importance as vital tools in the analysis of change detection at district and city level (Baboo and Devi, 2010). There are some environmental constraints in land use, for instance, climate, flora and fauna, soil characteristics and terrain. Data on LULC and prospects of their ideal use is essential for selecting, designing and implementing land use schemes to fulfil the growing demands for fundamental human needs and well-being. Also, this crucial information contributes to monitoring the land-use dynamics resultant of changing anthropogenic demands. The Western Ghats, which includes Kerala as well, is a designated World Biodiversity Hotspot, because of its vulnerability and richness (Myers *et al.*, 2000; Kerala Forest and Wildlife Department, 2016). The forest cover of Kerala is 2.74% of the national average, despite its geographical area being only 1.2% of India (Forest Survey of India, 2015). Idukki District tops the state's district forest cover i.e., 2713.72 km² (Forest Survey of India, 2015) and Devikulam Taluk in Idukki accounts for more than one-third of this. Therefore, the data accessible on LULC changes can contribute significantly in decision-making for efficient environmental management and future planning.

Within the past few decades, the Western Ghats has experienced accelerated deforestation because of the large-scale transformation of forest land for infrastructure development, fuelwood and monoculture plantations of tea, coffee and other commercial crops (Menon and Bawa, 1997). Furthermore, these LULC

changes occurring rapidly within the Western Ghats pose severe implications for the region's biodiversity. In this scenario, both changes in landscape and biodiversity distribution within the region have a strong spatial correlation (Menon and Bawa, 1997; Liping *et al.*, 2018; Ramachandra *et al.*, 2018).

Land degradation and deterioration primarily occur because of population pressure that causes intensive land-use changes without the correct planning and proper management practices (Prakasam, 2010; Kim, 2016). This leads to a population shift towards more vulnerable areas such as highlands (Lakshumanan *et al.*, 2012). In these vulnerable areas, land use without consideration of a variety of imperative aspects like erodibility and slope results in serious erosion and other associated problems. The impacts of landscape disturbing activities, like road construction, on erosion and landslides in hilly regions are well known (Vijay *et al.*, 2016). Due to extensive human activities, the forest cover is constantly declining and at the same time, the land under built up is increasing. In recent times, the functioning of the real estate personnel and property advertisers are conveying a serious threat to forest land and farming areas, which prompts unsustainable land-management conditions (Thirumalai *et al.*, 2015). In this scenario, studies associated with LULC change detection are imperative to figure out the real baseline condition and plan accordingly. Deforestation is the major environmental issue prompting degradation of the ecosystem of the Western Ghats (Kumar, 2005). Forestlands have been reported to be cleared in the past for various activities like the expansion of agriculture, plantations, and other developments (Jha *et al.*, 2000).

The abovementioned land-use changes have affected the ecosystems of Kerala forests in two considerable ways; firstly, a noticeable shrinkage of Kerala's forest covers and, secondly, loss of structural integrity of the residual forestland. As a result of several activities like forest degradation, unscientific farming practices, encroachment and over-exploitation of forest resources, the high range zones are now under constant risk of biodiversity loss and environmental degradation (Kumar, 2005; Reddy *et al.*, 2016).

Land use and land cover change studies have turned into a focal segment in recent strategies for management and monitoring of environmental resources and their changes (Adegboyega *et al.*, 2019). Raju and Kumar (2006) studied the land-use changes in Udumbanchola Taluk of Idukki District, which exhibited the changes leading to land degradation. Mani (2012) also carried out LULC change detection studies in Devikulam Taluk, Idukki district with main focus on major causes of forest deterioration in the area such as migration, agriculture, tourism, construction of roads and other physical infrastructures. As per the land-use change study carried out by Jha *et al.* (2000) in the Western Ghats, forests were cleared in the past for agricultural expansion, plantation development and for various other developmental activities. Further, in a report published by the Ministry of Environment and Forests, India, in 2013, LULC study carried out by

Kasturirangan illustrated that Idukki is dominated and deeply integrated by cultural landscapes along with unique ecologically sensitive natural landscapes. Ecologically Sensitive Areas (ESAs) taken up for agriculture, plantation and other activities were considered critical livelihood and economic mainstays of the region (Ministry of Environment and Forests, 2013). Recently, Reddy *et al.* (2013), analysed the deforestation rates and drivers of deforestation in India using remote sensing and GIS technology. Also, Reddy *et al.* (2013) studied long-term forest cover changes in Odisha and observed that the understanding of historical changes in Indian forests is inadequate. Another study carried out in the Western Ghats, Kerala indicated that deforestation between 1961 and 1988 was at an average annual rate of 0.28 (Prasad *et al.*, 1998). Similar change detection studies using remote sensing and GIS technology were carried out recently in different parts of the globe. Fortin *et al.* (2019) used multi-sensor LANDSAT images to quantify forest cover loss due to agriculture in Mato Grosso, Brazil. Scharsich *et al.* (2017), and Batool & Javaid (2018), carried out spatio-temporal land-use change study using LANDSAT images, in Matobo National Park, Zimbabwe, and Margalla Hills National Park, Islamabad, respectively.

The current study has been undertaken to assess the actual spatial and temporal trend in land use and land cover change over a period of three decades, and to assess the effects of increasing anthropogenic pressure on the biodiversity-rich and ecologically sensitive ecosystem of this area. LULC mapping and change detection analysis using multi-spectral LANDSAT images of Devikulam Taluk, Idukki District, Kerala was done using remote sensing and GIS. The present study examines the change in the LULC, with special focus on extent of built-up in the years 1988, 1999, 2008 and 2017 in the study area.

Study area

Devikulam Taluk of Idukki district was selected for this research. The map of study area showing the false colour composite (LANDSAT 8 imagery) of the site is given in Figure 1.

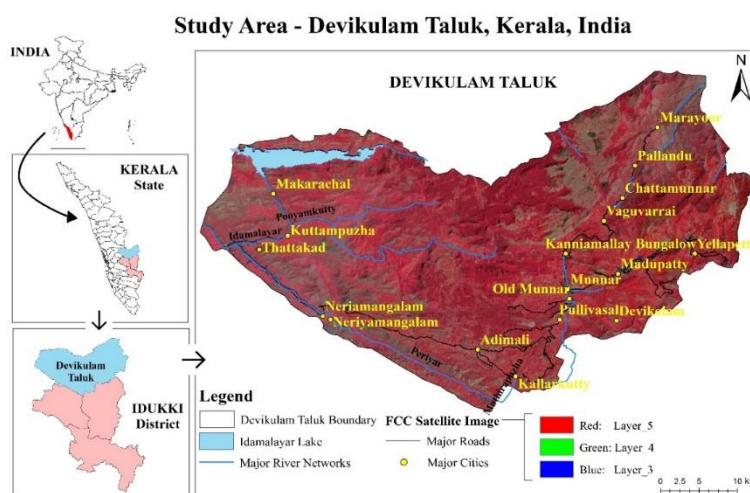


Fig 1. Study area map showing False Colour Composite (FCC) of the Devikulam Taluk, Kerala

Devikulam Taluk falls in the southern part of Western Ghats and is predominantly covered by the Shola forest ecosystem. The study site extends from 76°38'20" to 77°18'00" E longitude and 9°57'00" to 10°21'30" N latitude covering an area of approximately 1800 km². Two major rivers, the Periyar and the Chinnar, and many protected areas including, Eravikulam Wildlife Sanctuary (97 km²), Parambikulam Wildlife Sanctuary (274 km²), Indira Gandhi Wildlife Sanctuary (987 km²) and Chinnar Wildlife Sanctuary (90 km²), are present in and around the study area. This district is additionally bordering protected and reserved forests (RFs) further toward the west and east. Anaimudi (2,695 m), the highest peak in south India, is also a part of the high ranges of Devikulam Taluk. A large extent of this range has been retained as reserved forests and protected forests considering its significance as a support system for natural resources and as the watershed of many major rivers and minor streams arising from these slopes.

Devikulam Taluk has a total population of 177,621 as per the Census 2011 and consists of twelve villages. It includes Mannankadam, Kuttumpuzha, Mankulam, Kannan Devan Hills, Marayoor, Keezhanthoor, Pallivasal, Kanthalloor, Kottakamboor, Vattavada, Kunjithanny, Vellathooval, Anaviratty (Directorate of Census Operations, Kerala, 2011). The changing trend in the population of Devikulam Taluk is given in Table 1. Since 2001, its population density has increased from 140 people per km² (2001) to 169 people per km² (2011), which aided in the development of dense infrastructures within the major towns of Devikulam, such as Munnar. Even the number of households has increased from 44,268 (2001) to 45,480 (2011) in the same decade. As per the Kerala Tourism Statistics 2017, in Idukki District, Kerala, the number of total tourist visitors has drastically increased from 241,125 in 1999 to 1,132,371 in 2017. The growth figures point to the huge popularity Kerala tourism enjoys beyond the borders.

Table 1. Decadal variation in population in Devikulam Taluk since 1931

Population Growth in Devikulam Taluk since 1931 (Decadal variation in percentage)	
Year	Devikulam Taluk
1931	74.5
1941	10.14
1951	32.02
1961	48.38
1971	9.09
1981	33.48
1991	-2.48
2001	5.85
2011	-4.04

Source: District Handbook, Idukki, Census of India (2011)

Materials and Methods

Data used

For the analysis, satellite images obtained for the years 1988, 1999, 2008 and 2017, were LANDSAT TM (Thematic Mapper), ETM+ (Enhanced Thematic Mapper Plus) and OLI/TIRS (Operational Land Imager/Thermal InfraRed Sensor) satellite imagery with 30 m spatial resolution. All images used for analysis were restricted to one season only, i.e., winter, to avoid any seasonal variation in crops/plantations, deviating from the actual trend. Further, cloud avoidance in imagery was prioritized to focus on acquisition of higher quality scenes and repelling away from scenes with higher than nominal cloud density. In this way, we had a high possibility of acquiring scenes with a greater value for land-use change studies. Changes in land use/ land cover were detected using LANDSAT imagery, as they have a moderate spatial resolution of 30 m, which is optimal for classification and analysis of a large study area such as Devikulam Taluk (~1800 km²). Further, it has good radiometric as well as temporal resolution (16 days), an advantage in change analysis studies. LANDSAT spectral bands are also efficient in tracking land use and recording land change due to many natural and human-caused changes. The images, as mentioned in Table 2, were downloaded from the site <http://earthexplorer.usgs.gov/>.

Table 2. Details of the satellite imagery used in the study

S. No.	Satellite	Sensor	Date of Acquisition	Path & Row	Spatial Resolution
1	LANDSAT-8	OLI/TIRS	19-Feb-2017	144/53	30 m
2	LANDSAT-5	TM	27-Dec-2008	144/53	30 m
3	LANDSAT-7	ETM+ (slc-on)	09-Nov-1999	144/53	30 m
4	LANDSAT-5	TM	19-Jan-1988	144/53	30 m

High-resolution Google Earth imagery and topographical maps numbered c43l3, c43l4, c43l7, c43l8, c43k15, c43k16, c43k11, c43k12, c43r1, and c43q13, with the scale of 1:50,000 were used for the visual interpretation while carrying out the supervised classification and accuracy assessment of classified images of the study area. The vector database used in study area map preparation i.e., administrative boundaries, water bodies, roadways, major cities, etc., were downloaded from the site <https://www.diva-gis.org/Data> and verified using google earth imagery and topographical maps.

Image Processing and Land Use/ Land Cover Classification

After compiling the required data for the study, digital analysis of the data was carried out, i.e., processing of data (raster data such as satellite images, georeferenced topographical maps and vector data such as shape files), carrying out spatial analysis, and displaying information in graphical form, using geospatial software

and tools. Various Geographical Information System (GIS) and Remote Sensing techniques were employed for the preparation of different thematic layers and maps for assessing the land use modifications in the study area. The methodology adopted for performing this analysis is summarised as a flowchart in Figure 2.

After data acquisition, pre-processing of the satellite imagery was carried out, which included layer stacking, geo-referencing, atmospheric corrections, subsetting the area of interest from the imagery and other processes depending on the requirement of the study. All pre-processing techniques were carried out in ERDAS Imagine 2014 (Earth Resources Data Analysis System) Imagine and ENVI 5.3 (Environment for Visualizing Images) software. Georeferencing is one of the digital image pre-processing functions that is required prior to the main data analysis and extraction of information.

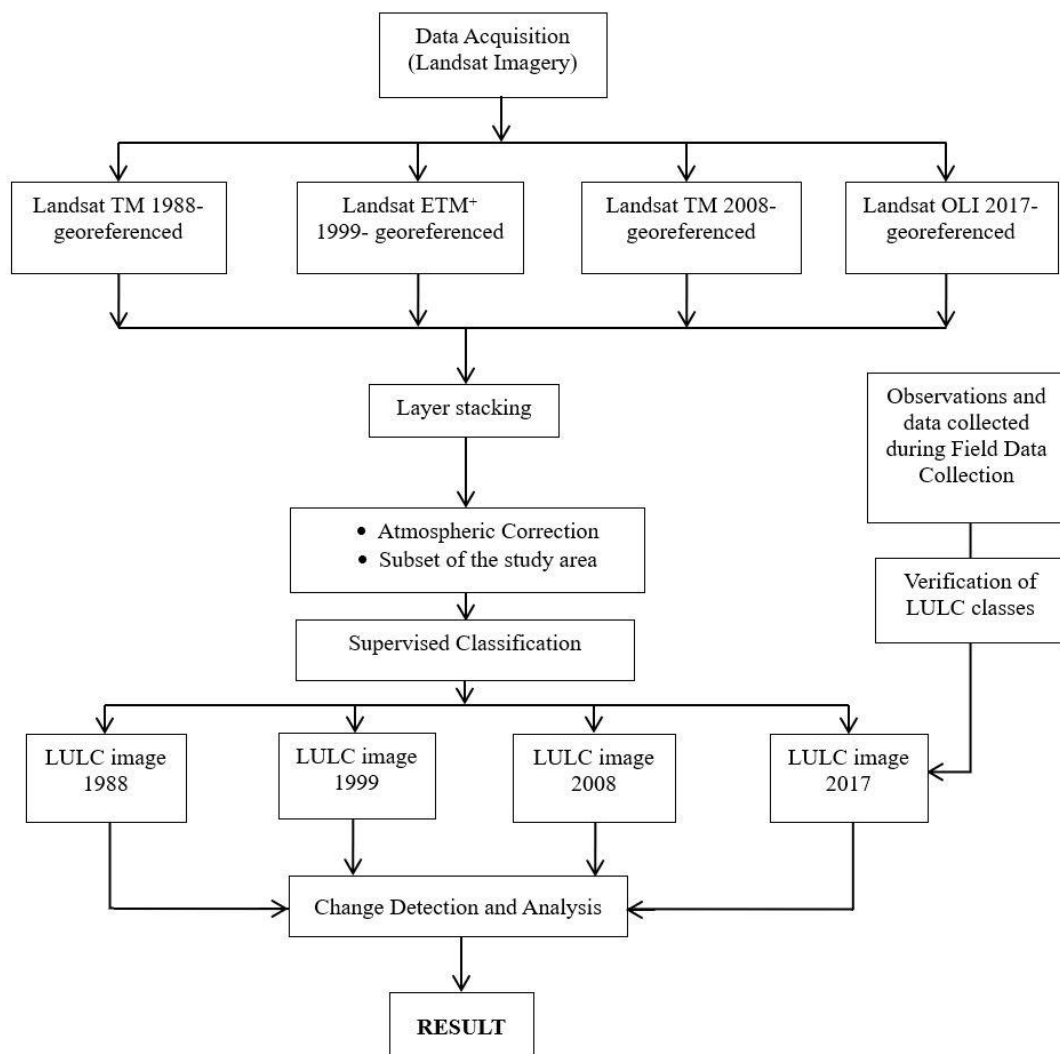


Fig 2. Flowchart representation of the methodology employed for carrying out the study

The topographical maps were georeferenced by selecting Ground Control Points (GCPs) throughout the area with a root-mean-square (RMS) error of less than 0.05 and projected in the projection system Geographic (Lat/Long) with spheroid and datum being WGS 84. The LANDSAT images were already geo-rectified

using GCPs and a digital elevation model (DEM) by USGS. Later, Atmospheric FLAASH (Fast Line-of-sight Atmospheric Analysis of Hypercubes) correction was applied to all satellite images using ENVI software. The main aim of carrying out atmospheric correction is to derive a good estimate of the true at-ground reflectance and to minimize the effects of atmospheric scattering. And finally, from the pre-processed imagery, the study area was extracted using the AOI (Area of Interest) boundary vector file and subset tool in the Raster tab of ERDAS IMAGINE 2014. The geometrically corrected and pre-processed LANDSAT 8 OLI/TIRS satellite image of the year 2017 was used for study area map preparation, along with the vector database in ArcGIS 10.1 software.

After pre-processing, the cloud-free LANDSAT TM, ETM+ and OLI/TIRS satellite imagery were used to generate LULC classified maps for the years 1988, 1999, 2008 and 2017. The Hybrid classification approach was employed, i.e., maximum-likelihood supervised classification (using training sites) and recoding (to refine the classified image) using ERDAS Imagine software. This classification method was selected as it assumes that the statistics for each class in each band are normally distributed and calculates the probability that a given pixel belongs to a specific class. Each pixel is assigned to the class that has the highest probability (that is, the maximum likelihood). Around 30 training sites per class were taken as the input of the same. Further, standard methods of visual interpretation techniques were used to interpret, classify and delineate land use classes based on the basic elements of interpretation, i.e., shape, tone, shadow, pattern, size, texture, location/site, height, resolution, and association. The land use/ cover classes were adopted from the Level I and II classification scheme described by Anderson *et al.* (1976) and modified according to the biogeography and land use of the study area. The classes finalized for the LULC classification were Water (II- streams, lakes, reservoirs), Forest and Plantation (II- deciduous forest land, evergreen forest land, mixed forest land, commercial plantations), Scrubland (II- herbaceous rangeland, shrubs and bushes, mixed rangeland), Cropland (II- nurseries, groves, vineyards, ornamental horticultural areas, other agricultural land), Barren/ Fallow land (II- sandy areas other than beaches, bare exposed rock, transitional areas, strip mines and quarries, mixed barren land) and Built-up (II- residential, commercial and services, industrial and commercial complexes, transportation, communication and utilities, mixed urban/ built-up land, other urban/ built-up land). High-resolution imageries in Google Earth and topographical maps were referred while delineating the LULC classes, and further recoding/cleaning of the classified images in ERDAS Imagine software. The software used for the study included ArcGIS 10.1, ENVI 5.3 and ERDAS Imagine 2014. ArcGIS software was mostly utilized for vector data processing such as thematic map preparation and efficient data management, whereas all the raster data processing like geo-referencing, image pre-processing, image classification, change analysis, etc., was carried out in ERDAS Imagine software.

Change Detection Analysis

Post-classification changes in LULC were analysed between maps of 1988, 1999, 2008 and 2017. Additionally, the population statistic information for Devikulam Taluk for the period 1931 to 2011 has been analysed. An important aspect of the LULC change detection study is to know the change 'from-to' process information of each category over a certain period, which can be used to clarify the magnitude, location and nature of the actual changes of an area (Lubis, 2011). We derived this information from the change matrix analysis. Change matrix was generated in ERDAS Imagine for the images 1988 and 2017, to analyse the changes in area under different LULC classes. The change map from 1988 to 2017 was also prepared to visually represent the spatial extent of major land use/ cover changes.

Accuracy Assessment

Accuracy Assessment of a classified product is a must and is used as a certification for further use in any information interpretation and further modelling. Accuracy of a classified image is generally determined by comparing certain pixels (a sample) of the classified map with the reference (for which the class is known) pixels (Sharma *et al.*, 2016). The source of reference pixels in this study were the GCPs (Ground Control Points) collected during fieldwork and randomly generated sample points in ERDAS Imagine software. A total of 102 GCPs and 600 randomly generated sample reference points (100 points per LULC class) were used to carry out accuracy assessment. The software automatically recorded the image class value for each point generated. Further, the high-resolution Google Earth imagery was used as a reference aid to manually input the reference class value for each point on the classified image. The overall accuracy of the classified image was produced by comparing how each of the pixels was classified versus the actual land cover conditions obtained from their corresponding ground truth data and sample reference points.

Results and Discussions

For the LULC classification, the study site was divided into 6 LULC classes, i.e., Water, Forest and Plantation, Scrubland, Cropland, Barren/ Fallow land and Built-up as shown in Figure 3. LULC maps were prepared for four different years viz. February 2017, December 2008, November 1999 and January 1988. Keeping in mind the fact that the similarity in spectral reflectance of the tree plantation and forest category could lead to misclassification, both the categories have been merged into one LULC class, i.e., Forest and

Plantation. Similarly, barren land and fallow land have been kept in one class based on similarity in spectral signatures. The LULC maps prepared for the study are given in Figure 3.

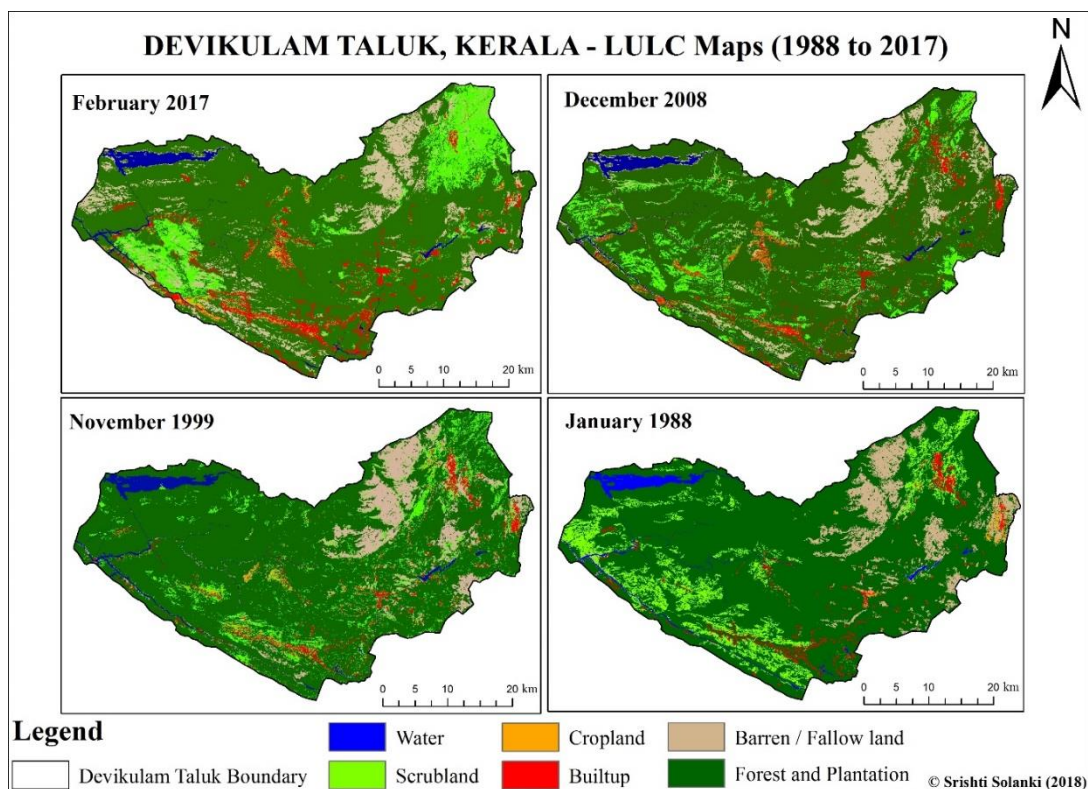


Fig 3. Land Use/Land Cover Maps of Devikulam Taluk generated for different time period, i.e., 1988, 1999, 2008, 2017

The LULC class-wise distribution of the area of Devikulam along with the graphical representation of the same for four different years, i.e., February 2017, December 2008, November 1999 and January 1988 has been given in detail in Table 3 and Figure 4, respectively. This post-classification change detection method has revealed that several changes in different LULC classes occurred in Devikulam Taluk over the study period. The gain/loss in different LULC classes over each decade has been given in Figure 5, highlighting major changes over this period.

As per the information presented in Table 3 and Figure 5, the largest increase between 1988 and 1999 was in area of barren/ fallow land with a gain of 28.39 km² and the largest LULC loss was observed in the scrubland LULC class, with a loss of 30.12 km², followed by forest and plantation class (12.58 km² loss). An increase in built-up with 6.49 km² gain was observed in this time period.

Table 3. Area Distribution in six LULC classes for different time period

S. No.	LULC Class Names	Jan-88		Nov-99		Dec-08		Feb-17	
		Area (km ²)	Area (%)	Area (km ²)	Area (%)	Area (km ²)	Area (%)	Area (km ²)	Area (%)
1	Forest & Plantation	1374.52	77.60	1361.94	76.89	1339.71	75.63	1247.24	70.41
2	Scrubland	172.43	9.73	142.31	8.03	154.84	8.74	191.10	10.79
3	Cropland	8.49	0.48	11.08	0.63	18.75	1.06	26.60	1.50
4	Water	40.22	2.27	45.47	2.57	37.38	2.11	40.86	2.31
5	Built-up	35.31	1.99	41.80	2.36	46.05	2.60	73.92	4.17
6	Barren/Fallow land	140.37	7.92	168.76	9.53	174.62	9.86	191.63	10.82
	TOTAL	1771.34	100	1771.36	100	1771.35	100	1771.35	100

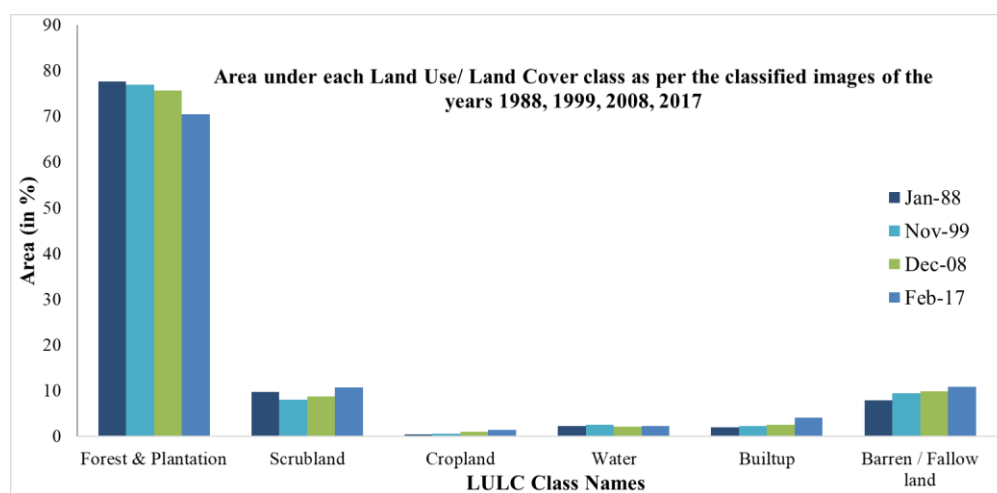


Fig 4. Area present under each LULC class as per the classified images of the years 1988, 1999, 2008 and 2017

Between the years of 1999 and 2008, the major increase in the scrubland area was recorded with a gain of 12.53 km² but with a large loss of 22.23 km² in forest and plantation area. Binutha and Somashekar (2014) carried out the future prediction of land cover in Devikulam Taluk using satellite images of 2000 and 2011; and observed a similar trend of forest area degradation in this area. The area under cropland and built-up also increased from 1999-2008, with a total gain of 7.67 km² and 4.25 km², respectively, which is supported by the trend followed in the study carried out by Mani (2012) in Devikulam Taluk. According to Mani (2012), a prominent change in settlement and the combination of mixed crops was observed from 1977 to 2004. Rapid colonization resulted in the conversion of forest to agricultural land from which a portion gets carved out for built-up areas (Binutha and Somashekar, 2014). However, the most drastic changes have occurred during the most recent decade under study, i.e., between 2008-2017, with a major forest loss of 92.47 km² and

an increase in area of LULC classes scrubland, built-up and Barren/ Fallow land, with a gain of 36.26 km², 27.87 km² and 17 km², respectively.

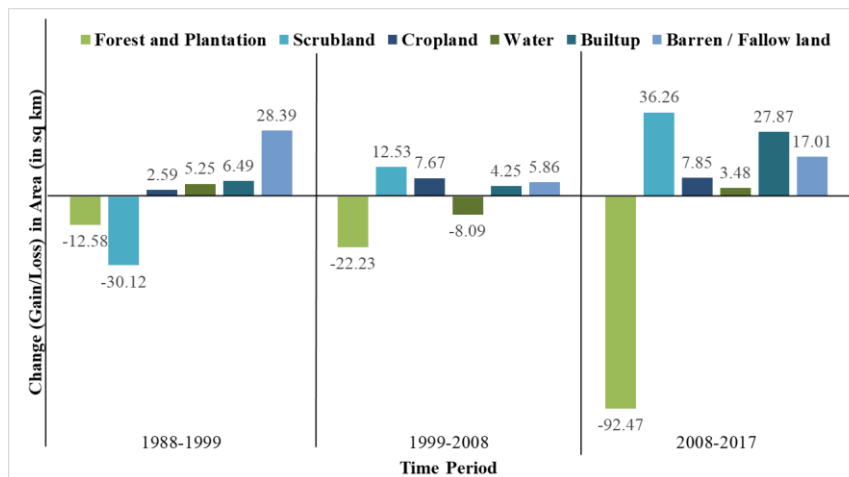


Fig 5. Variation in LULC classes within the decades, i.e., 1988-1999, 1999-2008 and 2008-2017, in Devikulam Taluk, Kerala

Major land use/ land cover changes that occur in forest, built-up and cropland classes over the years should be a root of concern. As evident from the data, forest cover has decreased over the years, which could be accounted to the fact that the Eucalyptus and tea commercial plantations have increased over the years. As these plantations have more monetary value compared to agricultural produce, people are allegedly shifting to the plantation. However, not much decrease in crops and agriculture has been encountered as per the study. But a major increase in agriculture has been observed from 2008 to 2017, which could be a positive sign. Waterbodies over the years have been well preserved as the extent of surface water has been almost constant throughout the years (from 1988 to 2017), with an increase of 0.62 km² in surface water.

Table 4. LULC transformation from one class to other class from 1988 to 2017

Area of LULC (in km ²) in 2017							
Area of LULC (in km ²) in 1988	LULC Classes	Forest & Plantation	Scrubland	Cropland	Water	Built-up	Barren/ Fallow land
	Forest & Plantation	1167.09	153.77	11.60	3.77	47.85	41.5
	Scrubland	73.69	40.9	2.59	0.64	0.82	31.83
	Cropland	4.23	-	0.21	-	0.93	0.39
	Water	2.17	-	0.1	35.1	0.27	0.2
	Built-up	5.23	8.39	0.68	-	10.85	0.6
	Barren/ Fallow land	45.34	3.11	0.36	1.46	2.75	76.96

Further, the classified images of the year 1988 and 2017 were used to calculate the transformation of the area from one LULC class to another. The results are presented in the form of a change matrix in Table 4. In this matrix, the diagonal elements represent the area of each class, which remains unchanged while the off-diagonal elements represent the changes in the area. To better understand and visualize the change from 1988 to 2017, a change map was also developed with a focus on major changes like built-up, which is represented in Figure 6. The matrix reveals that over this period of approx. 40 years, the increase in built-up was largely caused by the conversion of forest and barren land. The second-largest increase in LULC was found to be in barren/ fallow land, which gained from the conversion of forest and scrubland. In a study carried out by T. Ramachandra and R. Ramabhadran and published by Nidheesh (2017), estimating LULC change in Devikulam Taluk from 1973 to 2016, the remote sensing data showed a massive increase in area under urban settlements and agriculture. The data substantiated official reports of rampant encroachment that facilitated the emergence of Munnar as a top tourist destination, a major cause of degradation of the region’s biodiversity (Nidheesh, 2017). Furthermore, the major decrease in LULC between 1988 and 2017 was in forest area with 153.77 km² converted to scrubland, 11.6 km² into cropland, 47.85 km² converted to built-up and 41.5 km² converted to barren/ fallow land. According to Nidheesh (2017), 7.71% of forest land in Devikulam Taluk doesn’t exist anymore, which conforms to the forest loss estimated in this study i.e., 7.16% forest loss from 1988 to 2017. According to Prasad *et al.* (1998), the annual decline rate of natural forest cover in Kerala was assessed to be 0.9 % for the years 1961-1988; and 3.6% between 1980 and 2016, according to Nidheesh, 2017, which is third highest proportion of forest land diversion among Indian states.

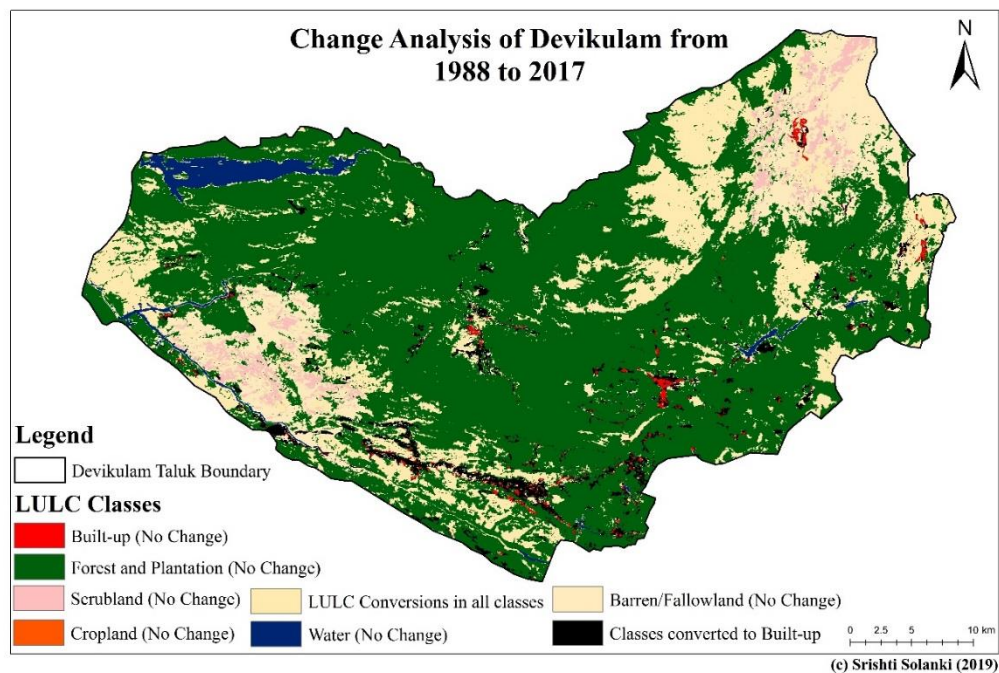


Fig 6. Change Map showing variation in Devikulam from 1988 to 2017

The LULC maps obtained from remote sensing and GIS may contain certain errors. Therefore, it is very important to assess the accuracy of the classified image. Accuracy assessment of the LULC maps, given in Table 5, has been carried out with the help of 102 GCPs collected on the ground and 600 randomly generated sample points in ERDAS Imagine software.

Table 5. Table showing the overall accuracy of classified images

S. No.	Date	Overall Classification Accuracy (in percentage)	Overall Kappa Statistics
1	February, 2017	73.77	0.681
2	December, 2008	86.67	0.7428
3	November, 1999	88	0.7581
4	January, 1988	77.78	0.6643

The results suggested that there has been a drastic increment in the built-up area in Devikulam from 35.31 km² in 1988 to 73.92 km² in 2017. The total percent increase in built-up over the period of 30 years has been assessed to be 2.18 % of the total geographical area of Devikulam, i.e., an increase of 38.6 km². This could be due to the increasing anthropogenic pressure in terms of migration or booming tourism contributing to the increased demand for infrastructures. According to Mani (2012), a large volume of the population had migrated to the hills of Devikulam when tea plantation was introduced between 1940 and 1970. To cater to the masses, the land use of the study area was drastically modified (Mani, 2012). Since 2001, its population density has increased from 140 people per km² (2001) to 169 people per km² (2011), which aided in the development of dense infrastructure within the major towns of Devikulam Taluk, such as Munnar. Even the number of households has increased from 44,268 (2001) to 45,480 (2011) in the same decade (Binutha and Somashekar, 2014). Furthermore, as per the Kerala Tourism Statistics (2017), in Idukki District, Kerala, the number of total tourist visitors has drastically increased from 241,125 in 1999 to 1,132,371 in 2017. In a similar study carried out by Dey *et al.* (2018) in Dehradun, built-up showed a linear increase during 1972-2016, however, the tourist inflow was more than the local population, which concluded that population growth is not a significant factor in infrastructure development. Devikulam Taluk had witnessed 12 major landslides and 18 monsoon-related deaths in the floods. Change in land use patterns had aggravated misery in this area (Shaji, 2019). This increasing anthropogenic pressure over this ecologically diverse and sensitive zone and the unhealthy and unsustainable approach of unplanned land use and management could have a disastrous impact over the area. Therefore, there is a need for appropriate land use planning, which is fundamental for sustainable development of this biodiversity hub.

As discussed above, the built-up area expansion and forest coverage decline have given a clear predictive picture of the anthropogenic pressure this area is bearing. Jha *et al.* (2000) showed that forest cover in the southern part of the Western Ghats (~40,000 km²) declined by 25.6% over the 22 years from 1973 to 1995. This will cause not just the loss of species and the degradation of unique biodiversity hotspot but will also affect rainfall patterns, river flow, water supply and climate across the whole region, causing grave ecological and environmental complications and complex feedback effects on agricultural production (Kumar, 2005). It is the presence of the important horticultural, agricultural species and rich biodiversity that aids in climate-proofing the region. Therefore, conservation of this unique habitat has to be taken up strictly as a movement at regional, district, state, national and global levels for the welfare of present and future generations.

Conclusion

This study has demonstrated the capability to successfully classify land use/ cover and carry out change analysis for such a large and heterogeneous area of Devikulam Taluk, using moderate resolution satellite data spanning approximately three decades. It is evident from the study that built-up and forest areas have shown pronounced change trends. From 1988 to 2017, the built-up has progressively increased, with a gradual decline in forest cover and is expected to follow similar trends in the future. This will further put direct or indirect pressure on the forest cover of the area, keeping in mind the population load, tourist inflow, and urban expansions. Devikulam Taluk, which is part of a major biodiversity zone of our nation, is under consistent danger of ecological debasement because of ill-advised land use planning and management. Many tourist destinations in Devikulam Taluk such as Munnar face problems of unscientific tourism flow, encroachments, and illegal constructions. Both scientific and administrative remedies are required for these issues.

A master plan focusing on the region's environmental sustainability is vital in such a case. Henceforth, the government should take effective and viable measures to protect the forestland and agricultural land in Devikulam Taluk. The prime focus needs to be on parts such as migration of people, plantation, agriculture, tourism and unplanned infrastructure development: the major causes of forest degradation in the study area. It has been observed that forest deterioration occurs in various parts of Western Ghats. If this trend continues several radical changes can be expected. This study, therefore, highlights the need to formulate policies, guidelines, and laws to restrict subsequent future degradation of forests and natural resources.

Acknowledgement

We thank our colleagues from University School of Environment Management (USEM), Guru Gobind

Singh Indraprastha University (GGSIPU) who provided insight and expertise that considerably assisted the research. We thank Prof. J.K. Garg, Senior Fellow, Department of Natural Resources, TERI School of Advanced Studies, and Prof. P. Bhattacharya, Professor, USEM, GGSIPU, for their constant guidance while conducting the research and comments that significantly improved the manuscript.

We would also like to show our gratitude to the Kerala Forest Department for their support throughout the course of this research.

Conflict of interest

None.

References

- Adegboyega, S.A., Oloukoi, J., Olajuyigbe, A.E. and Ajibade, O.E., 2019. Evaluation of unsustainable land use/land cover change on ecosystem services in coastal area of Lagos state, Nigeria. *Applied Geomatics*, 11(1), pp. 97-110. DOI: <https://doi.org/10.1007/s12518-018-0242-2>
- Baboo, S.S. and Devi, M.R., 2010. Integrations of remote sensing and GIS to land use and land cover change detection of Coimbatore district. *International Journal on Computer Science and Engineering*, 2(9), pp. 3085-3088. <https://pdfs.semanticscholar.org/9b2c/fcf1e5247941e987d4f08a4dab159e029206.pdf>
- Batool, R. and Javaid, K., 2018. Spatio-Temporal Assessment of Margalla Hills Forest by using Landsat imagery for year 2000 and 2018. *ISPRS- International Archives of The Photogrammetry, Remote Sensing and Spatial Information Sciences*, XLII-3, pp. 69-72. DOI: <https://doi.org/10.5194/isprs-archives-XLII-3-69-2018>
- Binutha, R. and Somashekar, R.K., 2014. Future prediction of land cover in Devikulam taluk, Kerala. *International journal of science and nature*, 5(4), pp. 677-683. [http://www.scienceandnature.org/IJSN_Vol5\(4\)D2014/IJSN-VOL5\(3\)14-16.pdf](http://www.scienceandnature.org/IJSN_Vol5(4)D2014/IJSN-VOL5(3)14-16.pdf)
- Dey, J., Sakhre, S., Gupta, V., Vijay, R., Pathak, S., Biniwale, R. and Kumar, R., 2018. Geospatial assessment of tourism impact on land environment of Dehradun, Uttarakhand, India. *Environ Monit Assess* (2018) 190: pp. 181(1-10). DOI: <https://doi.org/10.1007/s10661-018-6535-4>
- Directorate of Census Operations, Kerala, 2011. District Census Handbook, Idukki: Village and Town wise Primary Census Abstract (PCA), Directorate of Census Operations, Kerala. Website: http://www.censusindia.gov.in/2011census/dchb/3209_PART_B_IDUKKI.pdf (Accessed on 20 February 2019)

- Forest Survey of India, 2015. Forest Survey of India, India State of Forest Report (ISFR), Ministry of Environment & Forests, Dehradun. Website: www.fsi.nic.in (Accessed on 20 February 2019)
- Fortin, J.A., Cardille, J.A. and Perez, E., 2019. Multi-sensor detection of forest-cover change across 45 years in Mato Grosso, Brazil. *Remote Sensing of Environment*, 111266, pp. 1-14. DOI: <https://doi.org/10.1016/j.rse.2019.111266>
- Jha, C.S., Dutt, C.B.S. and Bawa, K.S., 2000. Deforestation and land use changes in Western Ghats, India. *Curr. Sci.*, 79: pp. 231-238. <https://www.jstor.org/stable/24103455>
- Kale, M.P., Chavan, M., Pardeshi, S., Joshi, C., Verma, P.A., Roy, P.S., Srivastav, S.K., Srivastava, V.K., Jha, A.K., Chaudhari, S., Giri, Y. and Murthy, Y.V.N.K., 2016. Land-use and land-cover change in Western Ghats of India. *Environmental Monitoring and Assessment*, 188(7): 387, pp. 1-23. DOI: <https://doi.org/10.1007/s10661-016-5369-1>
- Kerala Forest and Wildlife Department, 2016. Kerala Forest and Wildlife Department, Forest Statistics – 2016. Statistics Wing, Forest Headquarters, Thiruvananthapuram, Kerala. Website: <http://www.forest.kerala.gov.in/images/pdf/cov1.pdf> (Accessed on 24 January 2018)
- Kim, C., 2016. Land use classification and land use change analysis using satellite images in Lombok Island, Indonesia. *Forest Science and Technology*, 12(4), pp. 183-191, DOI: <https://doi.org/10.1080/21580103.2016.1147498>
- Kumar, B.M., 2005. Land use in Kerala: changing scenarios and shifting paradigms. *J Trop Agric*, 42: pp. 1-12. <http://jtropag.kau.in/index.php/ojs2/article/view/125>
- Lakshumanan, C., Pradeep, K.Y., Yiveganandan, S., Krishnakumar, P. and Muthusankar, G., 2012. Land use/Land cover dynamics study in Nilgiris district part of Western Ghats, Tamil Nadu. *International Journal of Geomatics and Geosciences*, 2(3): pp. 911-923. <http://www.indianjournals.com/ijor.aspx?target=ijor:ijggs&volume=2&issue=3&article=019>
- Liping, C., Yujun, S. and Saeed, S., 2018. Monitoring and predicting land use and land cover changes using remote sensing and GIS techniques—A case study of a hilly area, Jiangle, China. *PLOS ONE*, 13(7), e0200493. DOI: <https://doi.org/10.1371/journal.pone.0200493>
- Lubis, J.P.G. and Nakagoshi, N., 2011. Land use and land cover change detection using remote sensing and geographic information system in Bodri Watershed, Central Java, Indonesia. *Journal of International Development and Cooperation*, 18 (1), pp. 139-151. <https://pdfs.semanticscholar.org/8678/58a5a18d2fa769af9a57d588ff1e937747f9.pdf>
- Mani, K., 2012. Land use and land cover changes detection using multi temporal satellite data Devikulam Taluk, Idukki district, Kerala. *International Journal of Geomatics & Geosciences*, Vol. 3 Issue 1, pp. 1420-29. <http://www.indianjournals.com/ijor.aspx?target=ijor:ijggs&volume=3&issue=1&article=013>

- Menon, S. and Bawa, K.S., 1997. Applications of geographic information systems, remote sensing and a landscape ecology approach to biodiversity conservation in the Western Ghats. *Curr. Sci.*, 73: pp. 134-145. <https://www.jstor.org/stable/24098267>
- Ministry of Environment and Forests, 2013. High Level Working Group Report on Western Ghats - India Environment Portal, Ministry of Environment and Forests, Government of India. Website: <http://www.indiaenvironmentportal.org.in/content/383066/high-level-working-group-report-on-western-ghats> (Accessed on 10 September 2019)
- Myers, N., Mittermeier, R.A., Mittermeier, C.G., Fonseca, G.A. and Kent, J., 2000. Biodiversity hotspots for conservation priorities. *Nature*. 403(6772): pp. 853-8. DOI: <https://doi.org/10.1038/35002501>
- Nidheesh, M.K., 2017. Remote sensing data shows massive diversion of forest land in Munnar, LiveMint. Website: <http://www.livemint.com/Politics/ARHRnUhhK5TYUqcr9oodX/Remotesensingdatashowsmassivediversionofforestlandi.html> (Accessed on 08 August 2019)
- Prakasam, C., 2010. Land use and land cover change detection through remote sensing approach: A case study of Kodaikanal taluk, Tamil Nadu. *International Journal of Geomatics and Geosciences*, Vol. 1(2), pp. 150-158. <http://ipublishing.co.in/jggsvol1no12010/EIJGGS1015.pdf>
- Prasad, S.N., Vijayan, L., Balachandran, S., Ramachandran, V.S. and Verghese, C.P.A., 1998. Conservation planning for the Western Ghats of Kerala: I. A GIS approach for location of biodiversity hot spots. *Curr. Sci.*, 75(3), 211-219. <https://www.jstor.org/stable/24100954>
- Raju, K. and Kumar, R.A., 2006. Land use changes in Udumbanchola Taluk, Idukki District—Kerala: An analysis with the application of remote sensing data. *Journal of The Indian Society of Remote Sensing*, 34(2), 161-169. DOI: <https://doi.org/10.1007/BF02991821>
- Ramachandra, T.V., Bharath, S., Subash Chandran, M.D. and Joshi, N.V., 2018. Salient Ecological Sensitive Regions of Central Western Ghats, India. *Earth Systems and Environment*, 2: pp. 15-34. DOI: <https://doi.org/10.1007/s41748-018-0040-3>
- Ramachandran, R.M. and Reddy, C.S., 2017. Monitoring of deforestation and land use changes (1925–2012) in Idukki district, Kerala, India using remote sensing and GIS. *Journal of the Indian Society of Remote Sensing*, 45(1), pp. 163-170. DOI: <https://doi.org/10.1007/s12524-015-0521-x>
- Reddy, C.S., Dutta, K. and Jha, C.S., 2013. Analysing the gross and net deforestation rates in India. *Current Science*, Vol. 105, NO. 11, pp. 1492-1500. <https://www.currentscience.ac.in/Volumes/105/11/1492.pdf>
- Reddy, C.S., Jha, C.S. and Dadhwal, V.K., 2016. Assessment and monitoring of long-term forest cover changes (1920–2013) in Western Ghats biodiversity hotspot. *Journal of Earth System Science*, Vol. 125(1), pp. 103-114. DOI: <https://doi.org/10.1007/s12040-015-0645-y>

- Reddy, C.S., Jha, C.S. and Dadhwal, V.K., 2013. Assessment and monitoring of long-term forest cover changes in Odisha, India using remote sensing and GIS. *Environmental Monitoring and Assessment*, 185(5), pp. 4399-4415. DOI: <https://doi.org/10.1007/s10661-012-2877-5>
- Scharsich, V., Mtata, K., Hauhs, M., Lange, H. and Bogner, C., 2017. Analysing land cover and land use change in the Matobo National Park and surroundings in Zimbabwe. *Remote Sensing of Environment*, 194, pp. 278-286. DOI: <https://doi.org/10.1016/j.rse.2017.03.037>
- Shaji, K.A., 2019. Despite nature's protests, encroachment and illegal construction are rampant in Kerala's Munnar. Scroll.in. Website: [https://scroll.in/article/914935/despite-nature s-protests-encroachment-and-illegal-construction-are-rampant-in-keralas-munnar](https://scroll.in/article/914935/despite-nature-s-protests-encroachment-and-illegal-construction-are-rampant-in-keralas-munnar) (Accessed on 08 August 2019)
- Sharma, M., Areendran, G., Raj, K., Sharma, A. and Joshi, P.K., 2016. Multitemporal analysis of forest fragmentation in Hindu Kush Himalaya—a case study from Khangchendzonga Biosphere Reserve, Sikkim, India. *Environmental monitoring and assessment*, 188(10): pp. 596(1-18). DOI: <https://doi.org/10.1007/s10661-016-5577-8>
- Thirumalai, P., Anand, P.H. and Murugesan, J., 2015. Changing land use pattern in Nilgiris Hill environment using geospatial technology. *International Journal of Recent Scientific Research*, Vol. 6, Issue 4, pp. 3679-3683. <https://www.recentscientific.com/sites/default/files/2323.pdf>
- Vijay, R., Kushwaha, V.K., Chaudhury, A.S., Naik, K., Gupta, I., Kumar, R. and Wate, S.R., 2016. Assessment of tourism impact on land use/land cover and natural slope in Manali, India: A geospatial analysis. *Environment and Earth Science*, 75(1), pp. 20(1-9). DOI: <https://doi.org/10.1007/s12665-015-4858-9>