LAND SURFACE TEMPERATURE RESPONSES TO THE LAND COVER DYNAMICS IN WESTERN GHATS

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ABSTRACT

The Western Ghats is one among 35 global biodiversity hotspots has been experiencing unprecedented land use changes due to unplanned developmental activities. This has resulted in the alteration of landscape structure affecting the ecosystem functions. The implications of land cover transitions are evident from barren hill tops, lowered water retention capability of the catchment resulting in the conversion of perennial streams to the seasonal ones and also changes in the climate. Low rainfall and subsequent declaration of drought in all districts of Kerala in 2016 is the indication of mismanagement of natural resources (land, forests, water, etc.). The current study focuses on land cover changes in the Western Ghats since 2001. Land use changes were assessed using temporal remote sensing data - MODIS EVI (Enhanced Vegetation Index). Changes in the climate are assessed through computation of temporal land surface temperature (LST) through MODIS thermal data of 250m spatial resolution. The role of vegetation cover in maintaining LST has been evaluated.

The study reveals a loss of 2.49% of forest cover between 2001 and 2016 and plantations and agriculture/built up were increased by 1.62% and 1.12% respectively. The mean temperature of the region has increased from 30.9°C (in 2001) to 31.9°C (in 2016). The trends show an annual rise of 0.07°C in the study area. Multivariate analyses reveal that loss of forest cover is positively correlated with the LST. The current outcomes of the study highlight the need to evolve appropriate strategies to mitigate the changes in the climate through appropriate land resources management policies.

Keywords: Western Ghats, land Use, vegetation Indices, land surface temperature, multi-regression modelling

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1. INTRODUCTION

Land is the most important natural resource, which comprises of soil, water, and the associated flora and fauna. Land constitutes about 21% of the total earth's surface area and water bodies occupy rest of the area on Earth (ocean, sea, glaciers, lakes, rivers etc.). Land cover (LC) of a region refers to the observed bio-physical features on the Earth surface (Lillesand et al., 2004). Land Use (LU) is defined as human modified earth resources and is an outcome of socio economic factors. LC of a region influences the surface energy and the exchange of moisture, heat and momentum between the atmosphere and land surface (Botkin et al., 1984). As the anthropogenic activities on Earth surface continue to accelerate, the consequent LULC changes have resulted in the alteration in ecosystem functions with changes in the climate. The changes in LULC are issues of global concern due to large scale deterioration of environmental system. The impacts of LULC changes on climate can be divided into two major categories: bio-geochemical and bio-geophysical (Kabat et al., 2002). Bio-geochemical processes affect climate by altering the rate of flow of chemical substances between biotic (biosphere) and abiotic (lithosphere, atmosphere and hydrosphere) components of Earth. Bio-geophysical processes affect the physical parameters that determine the absorption and deposition of energy on Earth surface. The physical parameters are albedo, evapotranspiration, reflective properties, and absorptive properties of Earth (Gordon, 2008). The magnitude of changes are evident from the extent of transformation of forests/woodlands (6million sq. km) and grasslands (4.7 million sq. km) to crop land since 1700 AD (Goldewijk et al., 1997). The LULC changes are so wide spread that when aggregated globally affect the key aspects of Earth's functioning affecting the climate in a number of ways. Hence, LULC change analysis has become a prerequisite for managing natural resources and monitoring environmental changes.

Forests are large uncultivated tract of land covered with trees and underwood, woody grooves and pasture. Forests influence climate through physical, chemical and biological processes. Forests provide ecological, economic, social and aesthetic services to both natural systems and life forms (Gordon, 2008). The clearing of forests for cultivation, settlements and timber has altered climate, rainfall, temperature etc. Forests perform a series of vital environmental functions at local, regional and global levels. At local level environment services provided by forest include the maintenance of soil from erosion, water and climate.

On the global scale, forests have two fundamental functions: the role of carbon sinks in the global carbon cycle and as pools of biodiversity. The trees in forest hold an immense amount of carbon in trunk. When trees are cut, they let out carbon, which joins with oxygen to form CO_2, increases carbon content in the atmosphere and results in global warming. Deforestation increases the amount of release of CO_2 and other trace gases to atmosphere. When a forest is cut and replaced by cropland and plantations, an excess amount of CO_2 is released. In terms of social and economic importance and livelihood support, trees and forest occupy a central position in providing fodder for both domestic and wildlife in addition to being the main source of energy and building material for household (FAO, 2006).

The vegetation cover is one of the important components of the Earth's surface. It strongly influences evapotranspiration, infiltration, runoff, soil erosion and climate. The vegetation cover has been widely recognized as one of the best indicators for determining land condition (Booth and Tueller, 2003; Bastin and Ludwig, 2006; Wallace et al., 2006). The changing land use, would alter the rainfall pattern affecting the regional climate which may have long term implication like drought (Lin et. al., 2008; Warburton et. al., 2012). The changing land use and decline in rainfall leads to rise of temperature in a region. Tropical deforestation and desertification have been recognized as the most significant cause of land cover change. The reduction in forest cover has paved way to an increase of the mean temperature of Earth from 14.8°C (1980 - 2000) to 15.67°C (2000 – 2016) (Hansen., 2016). The temperature of a region determines the rate of evapotranspiration, climate, water-energy balance etc. With the increase in change in land use from forest to built-up, mono-culture (plantations), agricultural farms etc., the region has witnessed changes in mean temperature. The rise in temperature has direct implications on environment and life forms leading to their death due to heat wave, drought, etc. The rise in temperature of a region is studied through land surface temperature studies over a temporal scale.

The LST is the temperature of the skin surface of the land derived from satellite information or direct measurements. LST is a measure of the energy balance between Earth and atmosphere (Zhenming et al., 1989). They show a spatial heterogeneity and vary with differing land uses. They are different from air temperature, which is taken at a height of 2 m from the ground. The degree of LST is influenced by elevation, slope, aspect which exert control on incoming solar radiation (Dubayah, 1990). Variation in LST also may be subject to seasonality, time of day, sea breeze, surface air temperature, humidity, wind speed, and land use (Wang et al., 2008). In remote sensing terminology, it can be just called the surface radiometric temperature emitted by the land surface, observed by sensor at instant viewing angles (Prata et al., 1995). The studies on land surface temperature have helped us understanding the effects of rising temperature like the melting of snow in the Polar Regions, rising sea water levels etc. The low lying islands are threatened by rising water level which is a huge concern. Studies have shown forest cover helps in regulating the temperature of a region over other land use classes.

Landscape comprises of prime natural resources: soil, water and the associated flora and fauna interacting with each other and forming ecosystem. Globally, Land use Land cover (LULC) change is as old as human kinds (Helmer et al., 2000). The abrupt changes in landscape alterations are evident from increase in rate of change in past few centuries threatening humankind globally (Lambin et al., 2006). The rapid LULC changes exert detrimental and adverse impacts on environment and livelihood. The recent focus is on forest conversion because of its adverse impacts on global and regional climate change, soil degradation, loss of biodiversity and goods and services provided by natural system (Lambin et al., 2006). The change in climate can be attributed to changing LU pattern (Dutt et al., 2005). The monitoring of forest cover is essential for developing and implementing appropriate biodiversity conservation and carbon emission reduction policies (Defries et al., 2007). The quantification of forest cover is essential for forest resource management, land use planning, bio-mass estimation etc. Land cover mapping and monitoring has been done with the spatial data acquired through space borne sensors at regular intervals (i.e. Remote sensing data).

The assessment of forest cover is essential to understand LULC changes of the region. Prior to remote sensing technology forest cover changes have been quantified through field visits by measurement of canopy cover (Jennings et al., 1998), identification of faunal diversity (Peterken et al., 2003), permanent sample plot techniques (Synott et al., 1992) etc. The traditional methods of assessing forest cover are too complicated and demand huge resources and time consuming. The use of satellite data and GIS has now gained momentum largely due to the advantages like synoptic coverage, consistency, global reach, precision etc. (Lambin, 1997). Remote Sensing is the process of deriving information about the earth's land and water surfaces using images acquired from an overhead perspective, using electromagnetic radiation in one or more regions of the electromagnetic spectrum, reflected or emitted from the earth's surface (Campell, 1996). LULC studies are usually carried out using sensors with spatial resolution between 30 to 1,000 m or large extents (Defries et al., 2007). Hansen et al., 2008 highlighted how earlier the global LULC mapping has been carried out using data acquired by AVHRR at coarser resolution, but with the launch of MODIS sensor in Terra (1999) and Aqua (2002) platform, the land cover mapping has become easier using time series data. The Moderate Resolution Imaging Spectro radiometer (MODIS) satellite data products are reliable and useful for monitoring land cover changes. Even though it has a minimum spatial resolution of 250 m, the advantages include: high temporal resolution (ie., daily), data availability at no cost, wide range of data products etc. These characteristics allow land use mapping not only at global and national scales, but at regional and sub-regional scales as well.

Remote sensing has a long history with the aerial photographs taken from top of hills, air balloons, aircrafts etc. initially used for mapping. With the improvement in technology, development of platforms and sensors gained the thrust. Different platforms were developed to acquire data employing different methods. With the launch of LANDSAT – 1 in 1972, there has been a continuous large supply of remotely sensed data of Earth's surface. Post this era, the development in both sensors and mapping techniques reached a new level. The digital data acquired through remote sensing platforms are to be processed to acquire information. This process involving manipulation and interpretation of the digital spatial data is known as *Digital Image Processing* (Keifer et. al., 2014). The satellite data acquired have varying pixel values which are allotted to different land use classes and the whole process is known as *classification*. When the rules of classification are solely based on spectral radiances, the process is known as *spectral pattern recognition* and if the rules are based on geometric shapes, size, pattern etc. the process is called *spatial pattern recognition.* The *temporal pattern recognition* uses different periods of time as an aid in feature identification. Land use changes are identified through *temporal pattern recognition* of the same area. The classification schemes are usually based more on the spectral pattern of the satellite data. The classification schemes broadly based on spectral pattern of recognition are *supervised, unsupervised and hybrid* approaches.

The supervised learning is based on the sample training data. Using this method, the analyst has sufficient knowledge on pixels to generate representative parameters for each class of interest. This process is called training. Once trained the classifier is then used to attach labels to all the image pixels according to the trained parameters. The effectiveness of supervised classification largely depends on accurate estimation of pixels of each class during training. In an unsupervised classification, the prior knowledge of the classes is not required. The clustering is based on the spectral classes present in the image data. The spectral classes or clusters are compared with reference data to determine the identity and informational value of the spectral classes i.e. the information utility is defined by determining spectrally separable classes. There are numerous algorithms to determine natural spectral groupings present in data set: K-means, Fuzzy C means, hierarchical clustering, mixture of Gaussians etc. K-means is an exclusive clustering algorithm, Fuzzy C means is an overlapping clustering algorithm, mixture of Gaussian is a probabilistic clustering algorithm, hierarchical clustering clusters dataset into two kinds: similar and dissimilar (Guiliano et al., 2000). There are many hybrid approaches combining the advantages of both supervised and unsupervised classification like decision tree, neural network classification etc. The hybrid approach of clustering combines the supervised and unsupervised clustering techniques. The hybrid classifiers are useful in analyses where there is complex variability in spectral response patterns. It may be carried out by performing unsupervised classification initially to identify the numerous spectral classes that needs to be defined. This is followed by supervised classification wherein the spectral classes are classified using the training areas, which forms the hybrid approach. Even though both these approaches are common, the suitable approach of classification is based on the kind of data required to classify. Datasets that are too large are usually classified through unsupervised classification method followed by identification whereas smaller dataset are classified through supervised classification.

The first global LULC map through remote sensing data was prepared by DeFries et al. (1994) using maximum likelihood classification of monthly composited AVHRR NDVI data at 1° spatial resolution. Following this study, DeFries et al. (1998) used a decision tree classification technique to produce global land cover map at 8km resolution from AVHRR data. The launch of MODIS aboard Terra with 36 spectral bands provided a great improved basis for mapping and monitoring land cover data. Friedl et al. (2002) carried out global land cover mapping at 1km spatial resolution using data acquired from MODIS. The mapping was done using an algorithm containing two parameters global land cover at 1km and the land use dynamics at 1 km resolution. The analysis was carried out using supervised classification technique to classify into 17 land cover class globally following the IGBP standards. The global land map was classified at an accuracy of 75%. Even though there were some inadequacies in the map, the mapping remains the foremost in global modelling.

Chen et al. (2015) studied the human impacts on land system at a finer scale of 30 m resolution using images acquired by Landsat for 2001 and 2010. Since the analysis is carried on a global scale a large volume of data is involved which involved the use of automated approaches towards mapping. A pixel and object based method was used for classification. The land cover classification was carried out on the basis of split and merge strategy into 10 land cover classes. During classification, each land use class has been identified and extracted before proceeding further classification. The classification was based on pixel object knowledge wherein the pixels along with relief feature were taken into consideration. The classification could achieve an overall accuracy of 78.6%. Henderson and Gornitz (1984) studied the impacts of land cover transformation on climate change with emphasis on tropical deforestation. The deforestation of forests has been identified to be the major driver to land cover changes (Bolin, 1977). Of all the kinds of forest, the destruction of tropical forest is environmentally undesirable. The dense tropical forests have low infra-red emissivity which tends to absorb the incident short wave and inhibits the emission of long wave, thereby maintaining a positive net radiation balance. The inhibited thermal energy is used during photosynthesis and evaporation of water. The reduction in tropical forests also cause massive increase in run-off and soil erosion leading to flash floods and river sediment deposit (Delwaulle, 1973; Eckholm, 1973). The Western Ghats is one the tropical forests listed as global hotspots of biodiversity which is under a tremendous pressure of land use change. Menon et al., (1998) estimated the annual rate of deforestation in Western Ghats to be 0.57% in the period 1920-1990. The annual decline in forest cover of Kerala as assessed by Prasad et al., (1998) was found to be 0.9% annual for the period 1961-88.

Jha et al. (2000) estimated the changes in forest cover of Southern Western Ghats between 1973 and 1995. The study was conducted using satellite images acquired from Landsat MSS, 1973 and IRS 1B LISS-I, 1995. The supervised classification technique used for classification and categorized LU as forest and non-forest with an accuracy of 80%. It highlights a huge loss in the forest cover (40,000 sq. km) and biological diversity of Southern Western Ghats due to anthropogenic pressure. The study revealed an estimated a loss of 25.6% of forest cover in 22 years.

Ramachandra et al. (2014) conducted a study to analyse the land surface temperature and rainfall dynamics changing landscape of Western Ghats of India. The study was conducted using MODIS image derived NDVI (Kreigler et al., 1969) at a spatial resolution of 250 m.

$$\mathrm{NDVI} = \frac{\rho\mathrm{NIR} - \rho\mathrm{R}}{\rho\mathrm{NIR} + \rho\mathrm{R}}$$

ρ_{NIR} – Spectral reflectance in Near infra-red region

ρ_{R} – Spectral reflectance in red region

The study was carried out for the period 2003 and 2012. The study assessed the effect of land cover change on temperature and rainfall. The land cover classes were assigned on the basis of NDVI threshold and the land cover change during the period was assessed. The study revealed a consistent decline in dense vegetation cover in all 3 regions of Western Ghats i.e. north, central and south. The study revealed a significant correlation between NDVI and climatic parameters (rainfall and temperature). The study revealed a relationship between rainfall and land use pattern. The areas that receive lesser rainfall in the leeward side of the Western Ghats are often plains where agriculture is practised whereas the coastal side which has a tropical climate with annual rainfall around 1800mm supported plantation crops like rubber, coconut, tea etc. The study also revealed there is a decreasing trend in rainfall in the regions affected by loss of forest cover. Also another study by the same author reveals a massive diversion of forest land in Idukki district of Kerala at the rate of 3.6% in the period between the period 1980 and 2016. The study reveals a massive increase in the area under plantations, agriculture and urban settlements and reduction in open areas and forests.

Bharath and Ramachandra, (2012) conducted a study in Uttara Kannada district, Karnataka to analyse the spatio-temporal land use dynamics from 1973 to 2010 and the impacts of land use change. The study was conducted by analysing NDVI (Normalized Difference Vegetation Index) to assess vegetation at temporal level. The study was conducted by considering the agro-climatic zones of the district. The study revealed a trend of declining forest cover in the district, with forests giving way to monoculture plantations, agricultural activities and developmental projects. The study revealed an increase in number of patches and decline in class area of forest cover which clearly shows the declining trend of forest.

Kale et al. (2016) conducted a study to assess the pattern of LULC change in Western Ghats of India during 1985 to 2005 and project the future (2025) spatial distribution of forest using logistic regression and Markov model. The land use has been classified on the basis of IGBP classification scheme. The classification has been carried out using the land use vector layer of 2005 acquired from ISRO. The land use of 2005 was compared with the land use raster data set of 1995 and the land use change was updated. Similarly, the land use of 1995 was compared with the raster data set of 1985 and the land use change was updated. The land use transitions from 1985 to 1995, from 1995 to 2005 and from 1985 to 2005 were investigated. Other auxiliary data like population, temperature, slope, soil, road etc. that have been outsourced were used as drivers of land use change. The modelling of land use has been made possible using different modelling codes i.e. CLUE model based in Arc GIS, IDRISI, Markov Chain, Landis, urbanism etc. The spatial allocation of forest demand was predicted through logistic regression model based on Akaike Information criterion and area under receiver operating characteristic curve. There has been an increase in shrub land from 1985 to 2005. The study states there has been an increase in built-up at the cost of crop land in the period 1995 to 2005. The results for 2025 show a trend of forest degradation with greater probability of conversion of dry forest to non-forest. The forest cover of 2025 in Western Ghats is estimated to be about 37794 sq. km.

Setiawan et al. (2012) conducted a study to assess the change detection in land use and land cover dynamics at regional scale using MODIS Time-Series Imagery. The analysis of multi-year time series of land surface attributes (NDVI, EVI, LST etc.) and their seasonal change can indicate complexity land cover. The study was carried out using the wavelet transformed vegetation index EVI (Enhanced Vegetation Index), at 250m resolution from MODIS Terra platform between the periods January 2001 to December 2007.

$$EVI = G\frac{\rho\mathrm{NIR} - \rho\mathrm{R}}{\rho\mathrm{NIR} + \mathrm{C1} * \rho\mathrm{R} - \mathrm{C2} * \rho\mathrm{B} + \mathrm{L}}$$

G – Gain; C_1, C_2 - Aerosol coefficients; L – Soil Adjustment Vegetation Index

ρ_{NIR} – Reflectance of NIR band, ρ_R – Reflectance of Red band, ρ_B – Reflectance of Blue band

The change detection between successive years was assessed on the basis of distance comparison as described by Bouman, (2009). The pixels identified with change in class were validated using Google Earth and high resolution aerial photograph. This study characterized the conversion of forested lands to agricultural lands; barren land to urban land etc. The study had identified climatic effects like drought that occurred during the study period by analysing the EVI data. This study recognizes the importance of studying multi-temporal data sets to identify possible changes in LC and vegetative phenology. The study revealed the LU dynamics occurring in forest land such as deforestation, reforestation and forest regrowth during the study period.

Guo et al. (2007) conducted a study to compare and evaluate the ability of two vegetation indices: NDVI (Normalized Difference Vegetation Index) and EVI (Enhanced Vegetation Index) in a diverse range of biome of North West China. The vegetation of this biome includes broadleaf forests, needle leaf forests, meadows, grasslands, steppes, scrub, desert and agricultural farms. The satellite results are validated using CE 313 that has five filters between 450 and 1650nm to calculate vegetation indices over different vegetation types in different seasons. The results from satellite data proved NDVI shows a higher value than EVI and the difference between the two increased from deserts, steppes, cultivated vegetation, meadows to forest. There has been saturation of NDVI in high biomass types and the study recommends for EVI data in complex heterogeneous high biomass regions.

Dugarsuren et al. (2011) conducted a study to assess the LC change in Mongolia for a period of 10 years between August 2001 and August 2009. The land cover classification and change detection was carried out using a single stacked image of MODIS vegetation products and visible bands. The study followed a homogeneous classification wherein the complex land cover consisting of different types of forest cover, grasslands, and non-vegetated lands could be identified and categorized into 13 classes. The study recommends for homogeneous classification in complex terrains so as to reveal the spatio-temporal changes between different types of land cover. The study recommends to analyse the relationship of LC with temperature, precipitation etc. for further understanding of dynamics.

Setiawan et al. (2014) conducted a study on the seasonal dynamics of paddy field to analyse the cropping intensity of Java Island. The study enables to understand the effect of climate change on cropping pattern and postponement of cropping in non-irrigated lands. The study was conducted out using vegetation index EVI (Enhanced Vegetation Index) acquired from MODIS Terra 250 m platform. The data was analysed by looking at the time series trend of the cropland. The continuous fluctuation in EVI values all through the year determines if the land is cropland. The study was able to identify 8 different classes of cropland on the basis of intensity (single, double, triple etc.) and type of actual land class converted to cropland (upland, barren land etc.).

Wang et al. (2009) conducted a study to detect land cover change based on MODIS 250 m vegetation index (EVI). The study was conducted for the Dongjiang River basin in South Eastern China. The study was carried out by unsupervised isodata classification technique and decision tree classification method for land use land cover analysis in the period between 2001 and 2008. The 23 band EVI data are classified into 50 clusters which are evaluated using field survey data and high resolution images. Then rule based decision tree is built based on slope of terrain, land surface temperature etc. which are used to reduce confusion existing between different classes. The study has revealed a trend of declining forest cover, quantitatively indicated through the rate of change and transfer matrix. The study also reveals that classification carried out through hybrid classifiers have better accuracy and greater advantages.

Aide et al. (2012) conducted a study to identify the forest recovery trend in the Andes range of Columbia. The region was studied by mapping the land use land cover maps from 2001 to 2010 using MODIS (MOD13 250m) product coupled with reference data from QuickBird imagery and Google Earth to visually interpret the land use classes and for accuracy assessment. The study revealed that there has been a net gain in woody vegetation at national scale from 2001 to 2010. This increase in forest cover has been attributed to the establishment of protected areas. The study also reveals the advantage of MODIS data and the benefits of long term conservation planning. The regions prone to deforestation showed improvement with the establishment of eco-regions and protected areas.

Li et al. (2016) studied the potential and actual impacts of deforestation on land surface temperature (LST). The changes in forest cover modifies water, energy and carbon cycle of land surface in turn affecting the climate of the region are investigated. The study was conducted by calculating LST between forest and non-forest land features. The actual impact on temperature is quantified by analysing the trend of LST between deforested and non-forested land over several years. The study was conducted using the reference MODIS land cover data (Friedl et al., 2010) and Global Forest Change data (Hansen et al., 2013). The pixels were identified to be either forest or non-forest on the basis of a threshold set with at least 50% of pixel covered with trees, considering it to be forest. The forest change maps were created for the period 2000-2006 and 2008-2012. The LST data acquired from MODIS Aqua for the period from July 2002 to December 2013 was used for the study. The study revealed that deforestation increases T_{max} (maximum temperature) and T_{min} (minimum temperature) values in tropical regions and decreases both T_{max} and T_{min} in boreal regions. The high resemblance of air temperature with LST enables this kind of studies and this indeed helps us to understand the effects of land cover change.

2. Study Objective:

The forests in the Western Ghats have been undergoing rampant changes due to sustained anthropogenic pressure. The objectives of the study are to:

(i) Quantifying temporal LU changes from 2001 to 2016.
(ii) Understanding LULC dynamics with temporal land use change information and analysing change patterns.
(iii) Computation of LST and understanding LST response in coherence with temporal LULC changes.

3. STUDY AREA:

The study encompasses high biodiversity hotspot in South Western part of India, known as Western Ghats, extending from 8° to 21° N and 73° to 78° E covering a stretch of 1600 km through the states of Gujarat, Maharashtra, Goa, Karnataka, Kerala and Tamil Nadu. It covers an area 1, 60, 000sq.km. The hill range is interrupted by a 30 km break by the Palakkad (Palghat) Gap of Kerala. These mountain ranges are older than the great Himalayan, which emphasizes their importance. Due to its unique features and resources it is listed by UNESCO as one of the 35 biodiversity hot spots of the world (Meyers et al., 2000). Biodiversity hotspots are the regions that experience an exceptional concentration of plant endemism and experience high rates of habitat loss. The study area is known for high biodiversity, which offer the essential ecosystem services which account for only 3% of the India's land mass. Around 35% of the global ecosystem services are due to the of biodiversity hotspots, accounting only 2.3 % of Earth's surface. The study area along with the state boundaries is shown in Fig. 3.1.

This region has been under tremendous pressure due to its declining forest cover at rapid pace which prompted the Govt. of India to list the region under WPA, 1972. The WPA, 1972 was passed to protect animals and plants defining five types of protection viz. National Park, Wild life sanctuary, Conservation reserves, Community reserves and Tiger reserves (WPA, 1972). The region has 16 National Parks, 50 Wild life sanctuary, 2 conservation reserve. Even though conservation measures are adopted, the rate of deforestation has been accelerating in recent years. A report published by ATREE, Bengaluru estimates a loss of 2,729 sq. km. of forest in the Western Ghats during the period 1973-95 with an annual deforestation rate of 1.16%. The loss has been attributed to rise in plantations. Ramachandra et al., 2015 highlight serious LC changes in Western Ghats as forest cover decreased by 2.84%, 4.38% and 5.77% in the Northern, Southern and Central regions of Western Ghats. This has indeed affected the climate of the region with deficit rainfall, rising temperature. If plantations are taking over forest at this rate, then the forests would be destroyed in less than a quarter century (UN FAO, 2008). The rising human interference and building of dams has tremendously affected both flora and fauna of Western Ghats. There are around 1600 dams are built in Western Ghats with Maharashtra topping the list with 631 dams (Latha, 2009). As human and livestock population swell, forests shrink, which shows the relationship between rural communities and forest has become increasingly precarious. Nearly 90% of wood taken by rural communities is used as fuel and the forest is the source of fodder for over 100 million cattle heads of India.

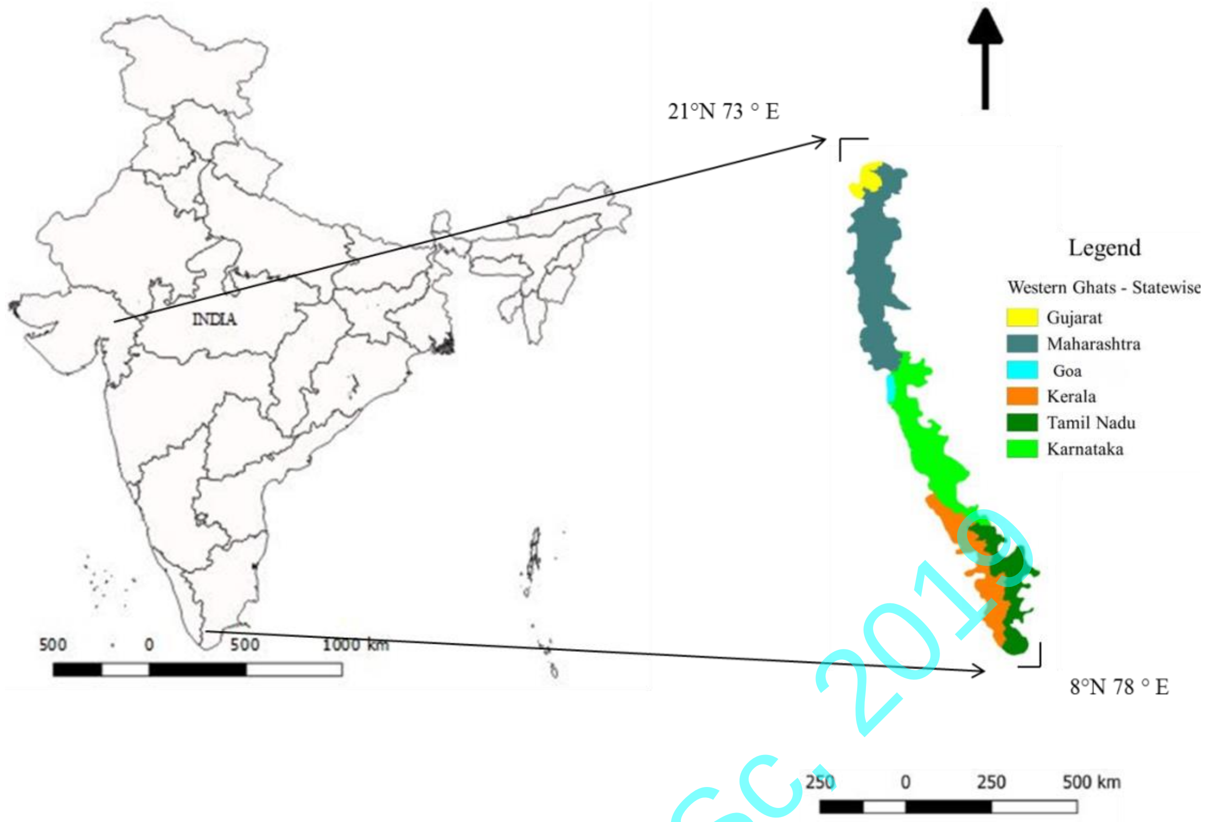

Fig. 3.1: Study Area – State wise

The Ministry of Environment and Forests, Govt. of India, set up a Western Ghats Ecology Expert Panel to study the degradation of Western Ghats and to suggest suitable measures in its protection. The commission headed by Prof. Madhav Gadgil submitted its report on 31 August, 2011 which recommended to declare 64% of the region as Ecologically Sensitive Area (ESA) zones. This sparked in protests against the implementation of the report as it was excessively environment friendly and not in tune with ground realities. Another High Level Working Group (HLWG) headed by Kasturirangan was set up to balance the concern of development and environment protection. This report recommended to declare 37% of area under Ecologically Sensitive Area (ESA) zone which has been accepted but fails in implementation till date.

3.1. Vegetation:

3.1.1. Forest Types: Western Ghats has 5 major forests and 23 floristic types based on ecological factors and floristic composition (FSI, 2015). They have been distinguished which are closely related to temperature and rainfall regimes. They are:

(i) **Tropical Wet Evergreen Forests:** Tropical Wet evergreen forests are mostly confined to windward side of the Western Ghats where the annual rainfall exceeds 2500 mm. These are further divided on basis of elevation into low (0 - 800m), medium (800 – 1450 m) and high (> 1,450m). These are tall trees with canopy reaching a height of 35-45m. The trees are arranged in tiers with each tier receiving different amount of light. The forest floor is in complete darkness. These forests have leaf all through the year and the shedding of leaves occur at a slow and steady rate all through the year. The leaves are pointed and narrow so that monsoon water flows off easily. These forests support lichen, mushroom and fungi that thrive on dead decaying matter. Climbers and lianas supported by sturdy trees, spiral towards canopy in search of light and fresh air (FSI, 2015).

(ii) **Tropical semi Evergreen Forests:** The steep eastern slopes of the Ghats where the annual rainfall is less than 1800mm harbour dry vegetation types. Their physiognomic features vary depending on moisture level of soil. Some of the valleys have evergreen forests that are distinct in floristic composition with its counterpart on Western side. These have two strata with canopy reaching a height of 12m from ground (FSI, 2015).

(iii) **Tropical Moist Deciduous Forests:** Moist deciduous forests are found in zone where the annual rainfall is in the range of 1600mm to 2000mm. These are a transition between wet evergreen and dry deciduous. Its presence indicates their secondary nature which has been formed after a possible degradation of wet evergreen forests. These are found at lower elevations in the coast and the eastern side which experience fairly long dry periods. These forests shed their leaves to survive the rigours of dry months to avoid loss of water through transpiration. With the pre-monsoon showers, a flush of fresh leaves appears to herald the beginning of fresh annual cycle. These forests have good timber trees (FSI, 2015).

(iv) **Tropical Dry Deciduous Forests:** Dry deciduous forests are found in areas where the annual rainfall is in the range of 800mm to 1500mm. These occur in climates that are warm year round and face drought during some months of the year. These are found towards the northern part and eastern side of Western Ghats. These form a canopy cover at a height of 10m. These forests shed the leaves during dry period to prevent loss of water through transpiration (FSI, 2015).

(v) **Grasslands:** In Western Ghats, natural grasslands are found above 1800m from MSL in Babudangiris, Kudremukh, Nilgiris, Anaimalai, Palani and Cardamom hill ranges. These are characterized by number of herbaceous and shrubby species mixed with grasses. The grasslands are also called shrub savannah or the sholas that have outlasted the gradual climatic and ecological changes over the last 20,000 years. This vegetation is found in hill folds that are attributed with stunted evergreen vegetation along with shrubby species and they do not form any strata (FSI, 2015).

3.1.2. PLANTATIONS: The hills of Western Ghats are dominated by different monocultures. Most of these plantations are exotics, which were introduced by the colonial rulers due to their high demand and commercial value. Post-independence the plantations continue to dominate the hilly agro systems. Tea and coffee were the first plantation (17th century) introduced to Western Ghats which are suited to the moist tropical climate for its growth. Teak plantation was first raised as monoculture in Nilambur, Kerala in 1844 and over the period this has attained prominence due to its high timber value. Over the years eucalyptus, bamboo, rubber, clove, acacia, coconut, cardamom, cinchona, Casurina sp. have displaced extensive patches of forest throughout Western Ghats. The hill ranges are also dominated with large number of ornamental plants and horticulture of temperate origin. Some unique landscape such as Myristica swamps were replaced by cultivation of rice, which has led to disappearance of swamp trees (Sathe et. al., 2003).

3.2 SOIL: The Western Ghats have a wide range of rocks and minerals that has given rise to different kinds of soils. The present system of 11 major soil groups is followed in the classification of soils in the study area (Rajan et al., 2013). The region is dominated with fertile Mollisols followed by Vertisols from southern to northern part. The presence of Ultisols in the Northern end of Western Ghats indicates a change in climate from wet to dry regime (Chandran, 1997). The soil map of the study area is shown in Fig. 3.2.

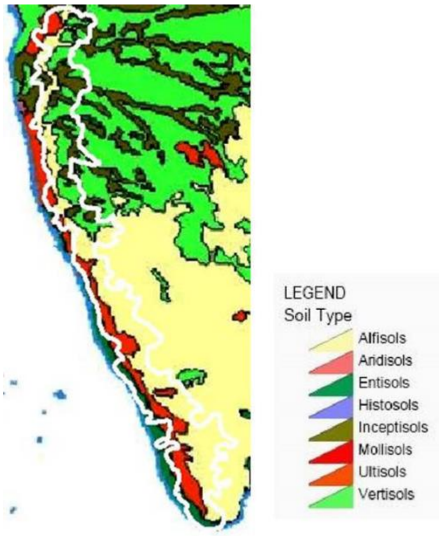

Fig. 3.2: Soil Map of Western Ghats

3.3. RIVERS: This region forms the catchment of area for complex riverine systems that drain almost the entire South India. The rivers originating in Western Ghats are classified into two major categories: west flowing and east flowing. The west flowing rivers are fast moving owing to the short distance travelled and steeper gradient forming estuaries. The east flowing rivers are slow moving due to the large distance travelled in the plains and eventually join Bay of Bengal forming large deltas. The data on prominent rivers originating from Western Ghats are described in Table 3.1.

Table 3.1: Prominent rivers of Western Ghats

East flowing Rivers		West Flowing Rivers	
Krishna	Bhima	Agnashini	Mahe
Godavari	Ghataprabha	Kallai	Chaliyar
Cauvery	Tungabadhra	Kadalundi	Periyar
Hemavat	Kabini	Sharavati	Bharathapuzha
Pennar	Tamiraparani	Netravati	Bedti
Palar	Vaigai	Mandovi	Kali

3.4. MOUNTAINS: The ranges of Western Ghats are known by different names at different locations ie. ‘Sahyadris’ in Karnataka and Maharashtra, ‘Sahya Parvatham’ in Kerala and ‘Nilgiri Malai’ in Tamil Nadu. The Western Ghats have some of the highest peaks (Figure 3.3) of the peninsular India with Anaimudi in Kerala scaling 2695m above mean sea level (MSL). The Eastern Ghats and Western Ghats converge at Biliririrangan Hills of Karnataka. The hill range has a number of pass like the Palakkad gap, Tamhini Ghat, Naneghat, Kasara

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Ghat etc. The northern portion of narrow coastal plain between Western Ghats and Arabian sea is known as Konkan coast, while the central portion is called Kanara and the southern portion is called Malabar. The foothills to the east of Ghats are known as Malenadu in Karnataka while it is Desh in Maharashtra.

3.5 RAINFALL: The Western Ghats regions are rain fed by the South West monsoon during the months of April to September. The rainfall of Western Ghats show two gradients i.e. the Western and the Eastern. These gradients are due to the differing relief of the Ghats. The relief of Ghats act as barrier to the Eastward movement of cloud masses brought by winds of South West monsoon. These cloud masses ensure an enormous amount of rainfall on the Western slopes of Ghats with an annual average of at least 2000mm. The Eastern slope of Western Ghats faces a drastic change with an annual average falling to 800mm. Table 3.2 describes the annual mean rainfall over two gradients. The annual rainfall of the study area is shown in Fig. 3.4.

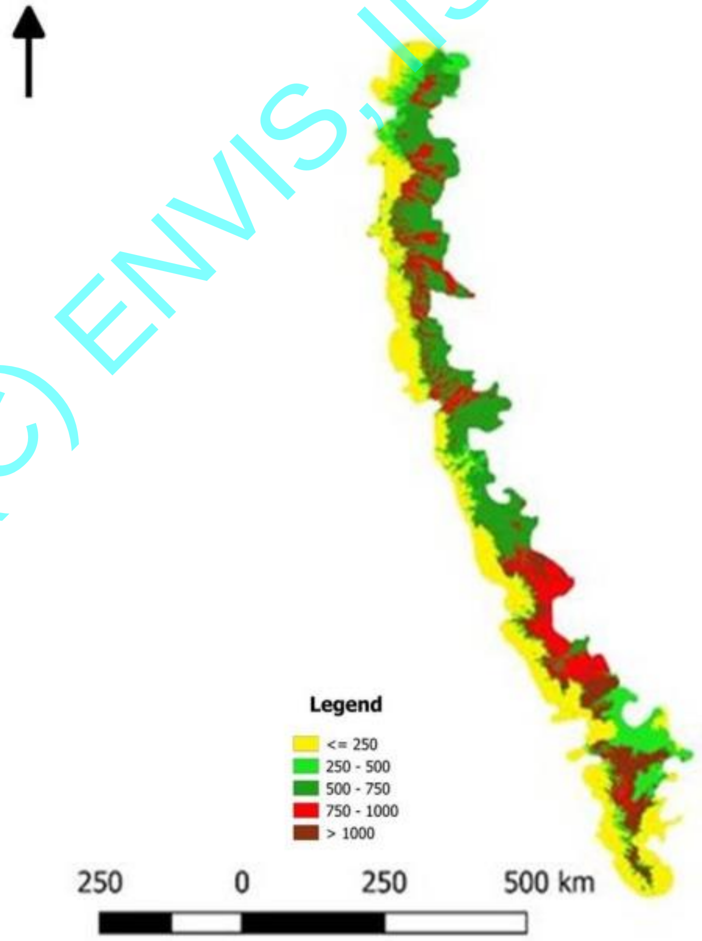

Fig. 3.3: Relief of Western Ghats

Table 3.2: Annual mean rainfall over 2 gradients of Western Ghats

	Western side	**Eastern side**
North Western Ghats	1900 to 3200 mm	800 to 1700 mm
South Western Ghats	2500 to 4000 mm	850 to 2000 mm

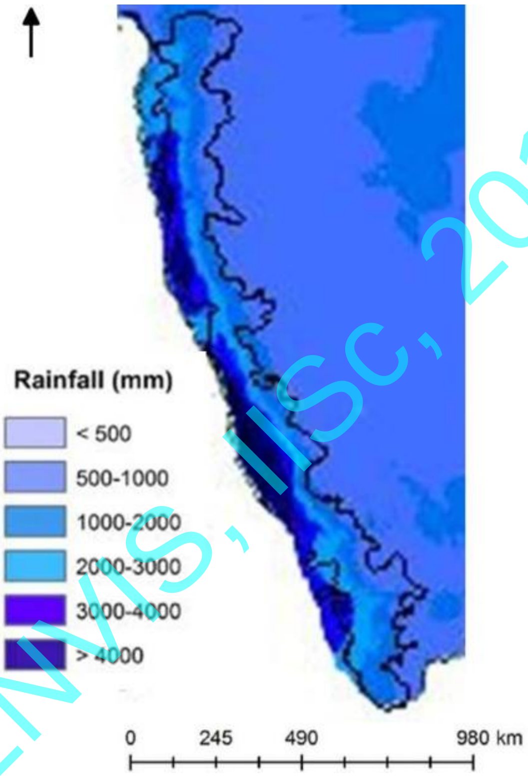

Fig. 3.4: Rainfall Map of Western Ghats

3.6 CLIMATE AND TEMPERATURE: The climate is humid and tropical in the Western side lower reaches due to the proximity to the sea. Elevations higher than 1500 and 2000m (AMSL) have temperate climate and average annual temperature is around 15°C at this elevation but there are drastic changes due to the changing vegetation practices of the region. At lower elevations the mean annual temperature varies from 20°C in South to 24°C in North. Table 3.3 describes the mean temperature over different months of the year in the study area.

Table 3.3: Annual mean temperature of Western Ghats

	Nov to Feb.	**March to May**	**June to October**
North Western Ghats	Max : 23° C Min : 5° C	Max : 42° C Min : 22° C	Max : 36° C Min : 20° C
South Western Ghats	Max : 29° C Min : 16° C	Max : 41° C Min : 24° C	Max : 33° C Min : 21° C

3.7. AGRO – CLIMATIC ZONE OF WESTERN GHATS: The study has been carried out on the basis of 3 major divisions of Western Ghats: Coast, Hill and Plains carved out of the Agro-climatic zone of India. The Tamil Nadu coast, Malabar coast, Karnataka coast, Konkan coast, Gujarat Region East constitute the coast of Western Ghats. The Maharashtra Sahyadri, Malnad, Tamil Nadu Ghat and South Sahyadri form the hills of Western Ghats. The Maharashtra plateau, Maidan (North&South) and the Coimbatore Madurai uplands constitute the plains of Western Ghats. The agro-climatic zones of Western Ghats are shown in Fig. 3.5.

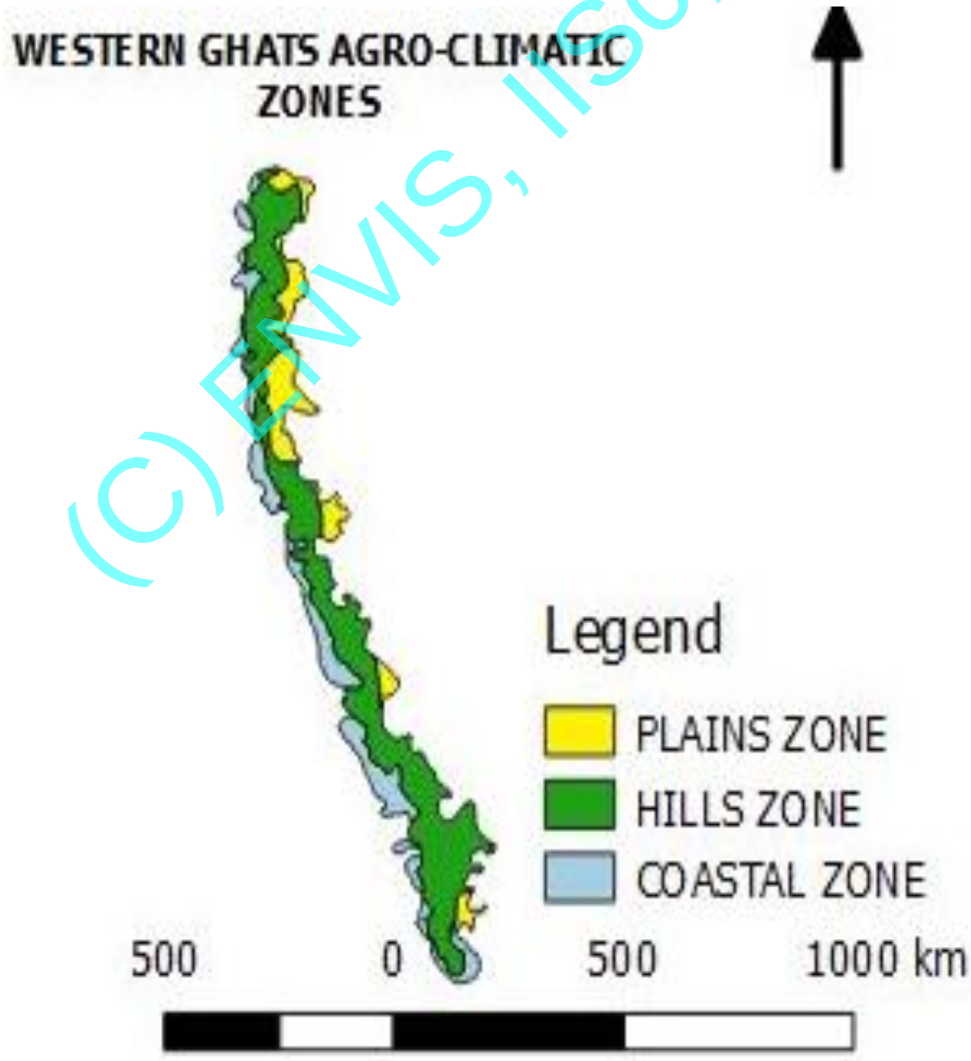

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Fig. 3.5: Agro Climatic Zones of Western Ghats

4. MATERIALS:

4.1. DATA PRODUCTS:

The data acquired by MODIS sensor present in TERRA platform has been analysed on temporal scale. The data has been collected through NASA LP DAAC which is a web user interface with an online search, discovery and ordering tool. MODIS, has 2330 km wide swath with revisit time of 1-2 days. It has 36 discrete spectral bands of differing spatial resolution (250m, 500m and 1000m) ranging in wavelength from 0.4 to 14.4 mm. The MODIS data products have improved our understanding of global dynamics and processes occurring on lands, oceans, and in lower atmosphere (Ren et al., 2008). The data products used in this study are MOD13Q1 (Vegetation Indices Product) and MOD11C2 (Land Surface Temperature Product). The tiles covering the study area are h24v06, h24v07, h25v07 and h25v08 are depicted in Fig. 4.1. The data has been acquired in the April months of 2001, 2008, 2015 and 2016 due to low cloud cover in the study area.

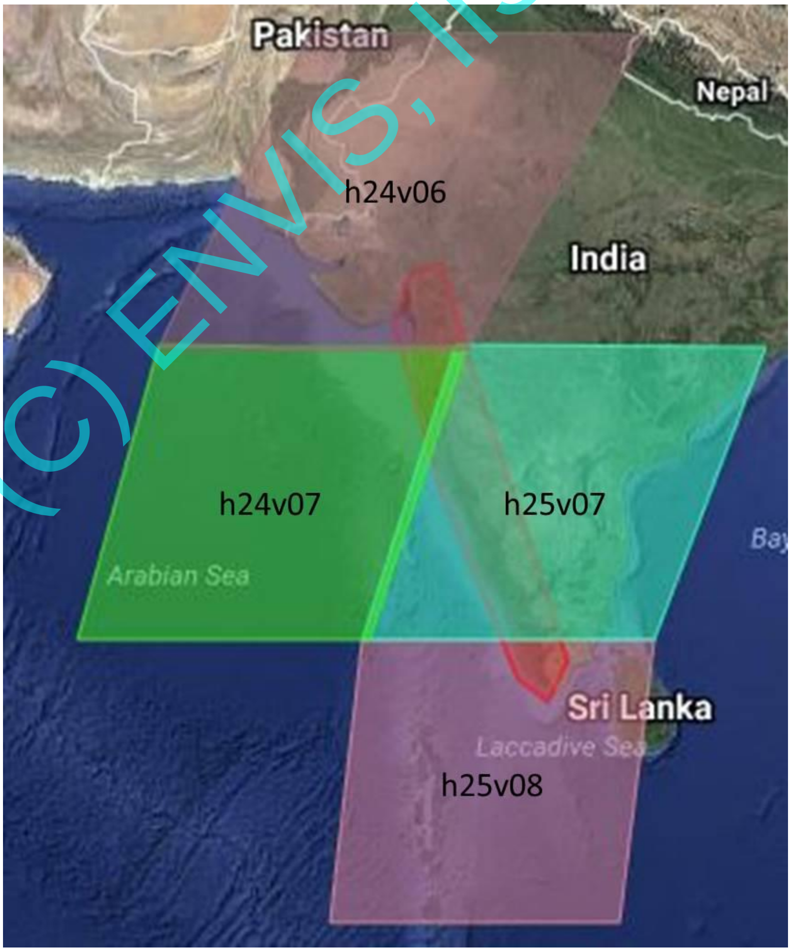

Fig. 4.1: MODIS tiles covering Study Area

4.1.1. MOD13Q1: The MOD13Q1 product provides Vegetation Index (VI) value at a per pixel basis which is available on a 16-day period. It has a spatial resolution of 250 m. There are 2 primary vegetation layers i.e. NDVI and EVI. This study has been carried out using Enhanced Vegetation Index (EVI) which has improved sensitivity over high biomass regions. The product is 16-bit signed data and the valid range is from -2000 to 10000. The EVI value from the satellite image has been obtained by using scaling factor 0.0001 (Huete et. al., 1999) as described in the metadata of the data product. The valid range of EVI is from -1 to +1.

4.1.2 MOD11C2: The MOD11C2 product provides land surface temperature (LST) and emissivity values at per pixel. This product is configured on a 0.05-degree latitude/longitude climate modelling grid (CMG). It is available on an 8-day period at a spatial resolution of 1km. The data has been resampled to 250m for this study.The product is 16-bit unsigned data and the value ranges from 7500 to 65535. A scaling factor of 0.02 (Wan et. al., 2007) is used to convert the reflectance value into temperature in Kelvin which has been further converted to degree Celsius.

$$\text{Temperature } (^\circ C) = (\text{Pixel Reflectance Value} * 0.02) - 273.16$$

4.1.3 GROUND DATA: The ground truth data for different land use classes i.e. forest, plantation, water-body, settlements, agricultural farms etc. collected have been used during analysis and validation. Google Earth data are also used for exploratory data analysis, validation and supervision of LU in the study area.

4.1.4. NASA CLIMATOLOGY RESOURCE: Global air temperature at 2 m from ground in 1° latitude and 1° longitude based on Climate Modelling Grid has been used for validation of LST maps. This data has been prepared using data acquired from different sensors and is available on a long term time series from 1983.

4.2. SOFTWARE TOOLS: The whole study has been carried out using free and open source software: GRASS GIS and Q GIS.

5. METHOD:

There have been extensive studies to understand the land use of Western Ghats by different researchers through different data, methods at different time periods. They have used field mapping, aerial photographs, satellite images etc. for inferring status of forests. The present study has been carried out by using satellite images to understand LU dynamics and the role of LU categories influence on LST. The two major approaches used for getting LU information from satellite imagery are visual interpretation and digital image processing. Visual interpretation uses various scene elements like size, shape, tone, texture, association etc. to identify and delineate objects. Digital image classification is the process of assigning pixels to respective classes on the basis of spectral properties (Lillisand et al., 2004).

5.1. Land Use Analysis:

The steps involved in preparation of LU maps are listed below and shown in Fig. 5.1.

(i) **Check for quality parameters:** The satellite images of the study area are checked for pixel quality and cloud cover using data quality and science quality flags.

(ii) **Image pre-processing and Geo-referencing:** The remote sensing data (satellite images) satisfying the quality parameters have been corrected for radiometric errors like faulty data lines, repeating lines etc. The image then has been corrected for geometric errors by nearest neighbourhood method using suitable ground control points obtained through field survey and from Google Earth. The geo-referenced images have been then projected to Geographic Coordinates System (EPSG: 4326).

(iii) **Image segmentation - Agro-Climatic Zones:** The satellite images have been cropped to different zones ie. coast, hills and plains using suitable masks based on the agro-climatic zone of the study area. These are further cropped based on state boundaries to study the change in LU classes over a period. These processes are carried out using different GIS software as discussed in the Materials section.

(iv) **LU classification:** The LU analysis has been carried out using supervised ISODATA (Iterative Self Organizing Data Analysis Technique) Classification technique. In ISODATA clustering, the image data are first classified by aggregating them into natural spectral groupings or clusters present in scene. The basic premise is that values within a given cover type shall be close together in measurement space; whereas data in different classes shall be comparatively well separated. Iterative Self Organizing Data Analysis Technique (ISODATA) is a widely used variant of K-means technique used for pattern recognition (Tou et al., 1974). The world '*self-organizing*' refers to the way clusters are located which are inherent in data. It uses the minimum spectral distance formula to form clusters (Chen et al., 2000). In this number of clusters are set initially and clustering has been carried out on basis of deletion, splitting or merging during the process (Fig 5.2). Once an iteration is completed with the assignment of pixels to the cluster, the statistics describing each cluster are evaluated. If the distance between the mean of two clusters are less than pre-defined distance the two clusters are merged. On the other hand, if a single cluster has a standard deviation that is greater than a predefined maximum value, the cluster is split in two. Clusters with fewer than the specified minimum number of pixels are deleted. The clustering is carried out until (i) a maximum number of iterations are performed, or (ii) a maximum percentage of unchanged pixels has been reached between two iterations.

Fig. 5.2 represents the process of ISODATA clustering into 'n' classes.

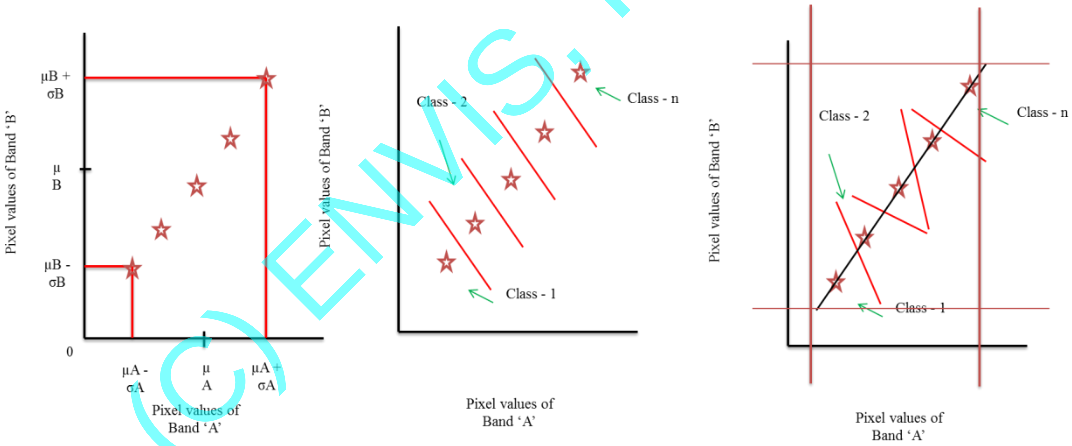

Fig. 5.2: ISODATA Clustering

The satellite image was first classified into 16 clusters over 10 iterations. During every iteration an arbitrary mean is assigned to each cluster and the pixels are allocated in the clusters closest to the mean. New means are calculated during each iteration for each cluster based on the pixels present. The process is repeated until each pixel is each pixel is assigned to the closest mean. Each of the clusters is separated out and individually compared with field data. If the clusters are found to be confusing between two classes, these are noted and those showing confusion are grouped and further classified by same algorithm (ISODATA). Confusions are found to exist during classification of LU between plantation and forest, built up and open spaces, crop land and scrub vegetation etc. The method of allocating the cluster to each land use class is based on the visual observation. The land use maps are prepared and categorised into these classes described in Table 5.1.

Table 5.1: Different Land use classes

Different Land Use Classes	
Forest	Evergreen and semi-evergreen – Dense Canopy
Scrub Vegetation	Degraded forest, Grassland, Dry deciduous – Open Canopy
Plantations	Rubber, coconut, teak, tea, coffee, areca nut, etc.
Water-body	Reservoirs, rivers, lakes etc.
Others	Agricultural land, Urban Built-up, Horticulture, Barren land

(v) Validation of LU Maps: The land use maps have been validated for classification error by computing Error matrix. The reference image has been prepared by classification of training sites taken from ground data. The Kappa coefficient analysis is a discrete multivariate technique used in accuracy assessment for determining statistically if one error matrix is significantly different from another (Bishop et al., 1975)

$$K = \frac{N\sum_{i=1}^{k} n_{ii} - \sum_{i=1}^{k} n_{i+}n_{+i}}{N^2 - \sum_{i}^{k} n_{i+}n_{+i}}$$

where: N – Total number of pixels

n_{ii} – Number of pixels correctly classified

n_{i+} - Number of pixels classified in row i

n_{+i} - Number of pixels classified in column

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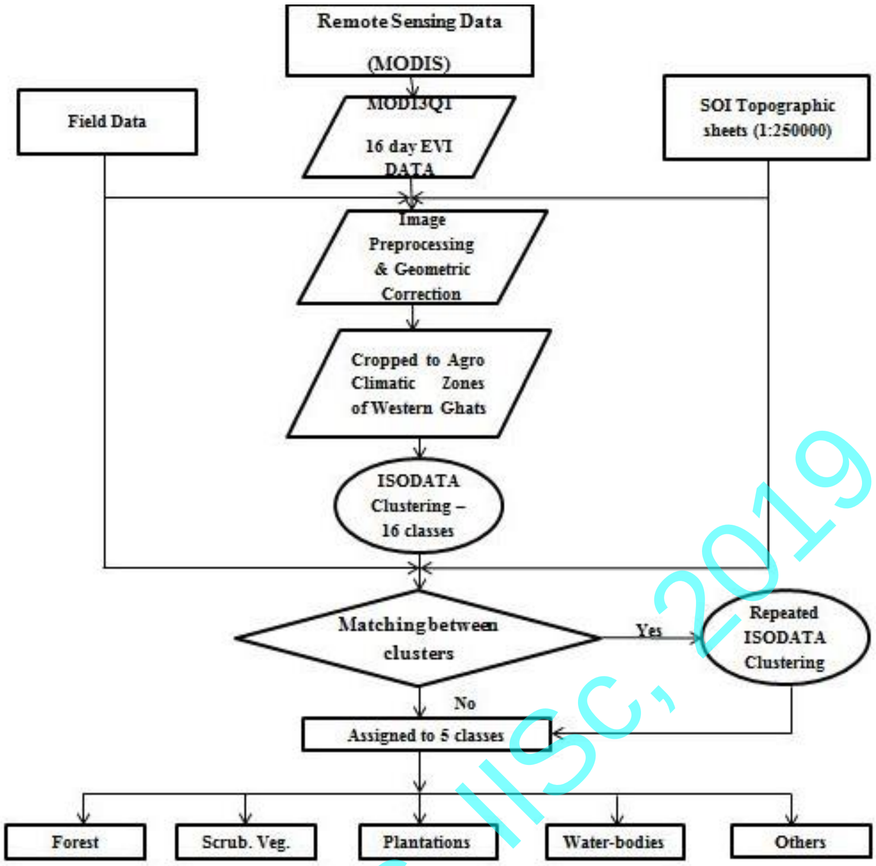

Fig. 5.1: Flow chart depicting preparation of LU map

5.2. LST MAPS: The steps involved in preparation of LST maps are listed below and show in Fig. 5.3.

(i) **Check for quality parameters:** The satellite images are checked for pixel quality and cloud cover using data quality and science quality flags.

(ii) **Image pre-processing and Geo-referencing:** The satellite images satisfying the quality parameters have been corrected for radiometric errors like faulty data lines, repeating lines etc. The image then has been corrected for geometric errors by nearest neighbourhood method using suitable ground control points obtained through field survey and from Google Earth. The geo-referenced images have been then projected to Geographic Coordinates System (EPSG: 4326).

(iii) **Image segmentation - Agro-Climatic Zones:** The satellite images have been cropped to different zones i.e. coast, hills and plains using suitable masks based on the agro-climatic zones of the study area. These are further cropped onto by state boundaries to understand the change in land use classes over the study period.

(iv) **Land Surface Temperature Maps:** The LST based on agro-climatic zone has been evaluated. The maximum temperature Ts_{max}, minimum temperature Ts_{min} and mean temperature Ts_{mean} have been evaluated for different zones of the study area.

(v) **Validation of Land Surface Temperature Maps:** The LST maps has been validated on the basis of air temperature (at 2m) taken at 13 different locations all across the study area. The ground data has been taken from NASA Climatology Resource – Global Coverage. The reference data set provides air temperature at a height of 2m from ground level. The ground maximum temperature Tg_{max}, minimum temperature Tg_{min}, and mean temperature Tg_{mean} is compared with land surface temperatures (Ts_{max}, Ts_{min} and Ts_{mean}) for the same locations. A mean land surface temperature of about 2-3 °C higher than air temperature is deemed to be acceptable (Cheng et al., 2005).

6.3. Rate of Land Use Change: The rate of change of each land use category is shown by two indices i.e. total changed area A, and the rate of change ρ. These are calculated as follows:

$$A = |(a_{t1} - a_{t0})|$$

$$Rate\ of\ Change\ \rho = \{[Ln(a_{t1}) - Ln(a_{t0})]/(t_1 - t_0)\} * 100$$

Where a_{t1} – area in current year, a_{t0} – area in base year, t_1 - current year, t_0 – base year and Ln is natural logarithm.

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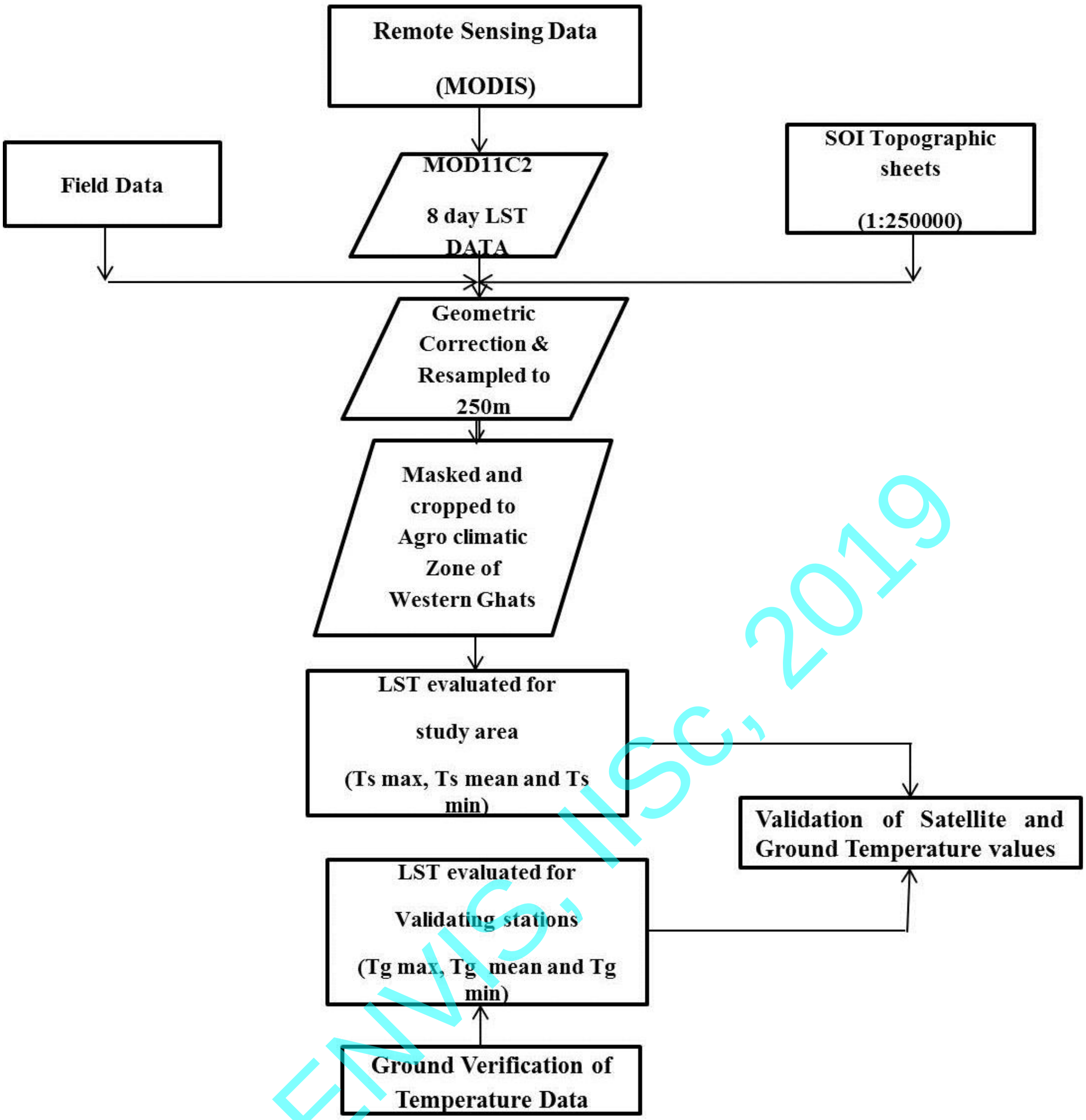

Fig. 5.3: Flow chart depicting preparation of LST map

6. RESULTS AND DISCUSSIONS

6.1. Spatio temporal LU change analysis: The LU maps have been prepared from MODIS EVI data for the years 2001, 2008, 2005 and 2016. The Enhanced Vegetation Index (EVI) is an optimised vegetation index designed to monitor vegetation cover in high biomass region due to its reduced atmospheric effects (Franklin et al., 2002). The LU maps at different time scale based on the states covering Western Ghats have been prepared. Table 6.1 describes the relative percentage of study area to area of state. Fig. 6.1 shows the area of state to study area in that state.

Table 6.1: Percentage of study area in Western Ghats to total area of state

States	Study Area (ha)	Area of state (ha)	%
Gujarat	556949.27	19602400	2.84
Maharashtra	5768323	30771300	18.75
Goa	184747.57	370200	49.90
Karnataka	4221595	19179100	22.01
Kerala	2792972	3886300	71.87
Tamil Nadu	2482776	13006000	19.09
Western Ghats	16007362.84	86815300	18.44

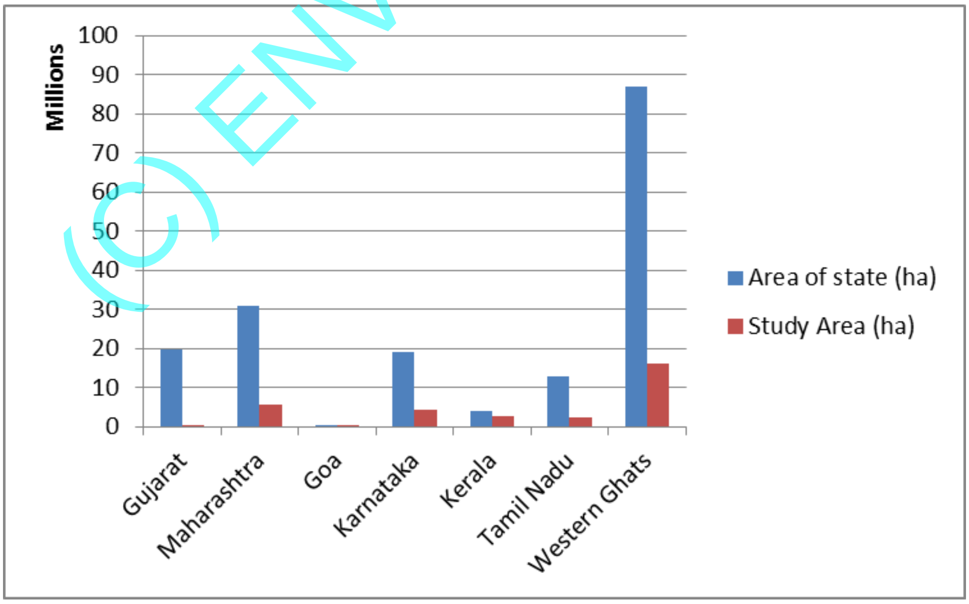

Fig. 6.1: Area of state to study area

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6.1.1 Time Series MODIS EVI based LU change Analysis from 2001 to 2016 – Kerala:

Kerala, located towards the Southern end of the Western Ghats supports a rich flora and fauna. The state in the last few decades has been undergoing rapid changes in the land use due to rise in commercial plantations. This has led to serious impacts on forest eco-system with shrinkage in the state's forest cover and the loss of structural integrity of the remaining forest (Kumar et al., 2005). The forest cover of Kerala is largely spread over the Western Ghats bordering the state. Even though the state has a recorded forest cover of 11125.59 sq. km.(28.9% of the total area of the state), the actual forest cover is only 9400 sq. km. The state has a large area under plantation and the diminishing forest has impacted the state with rising temperature, soil erosion, silting of rivers, water scarcity, and drought conditions etc. Fig. 6.2 shows the spatial extent of change in land use during the period 2001 to 2016. Coastal regions are majorly dominated by dense commercial plantations by disturbing ecology.

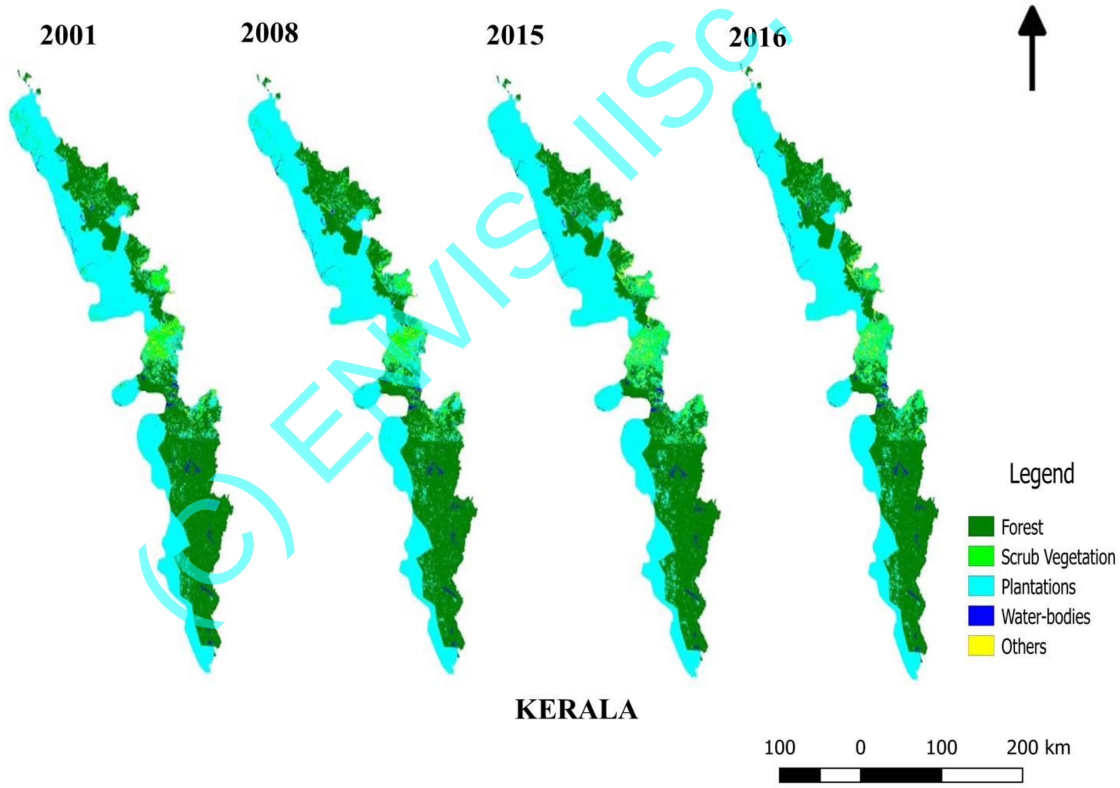


Fig. 6.2: Spatial extent of LU changes in Kerala from 2001 to 2016.

The error matrix has been computed but has not been shown due to the large spatial and temporal nature of the data. The kappa has been ranging from 0.76 to 0.83 for different zones of Kerala. Table 6.2 shows the area under different land use classes with respect to the total area under study of the state. Fig. 6.3 shows area under different land use class in the study period from 2001 to 2016.

Table 6.2: Area under different LU class - Kerala

Area	**2001**		**2008**		**2015**		**2016**	
Kerala	**ha**	**%**	**ha**	**%**	**ha**	**%**	**ha**	**%**
Forest	1317725	47.18	1286647	46.07	1263791	45.25	1262127	45.19
Scrub Veg.	130261	4.66	131455	4.71	134859	4.83	135679	4.86
Plantations	1288366	46.13	1316574	47.14	1334237	47.77	1334987	47.80
Waterbodies	26425	0.95	26436	0.95	26424	0.95	26512	0.95
Others	30195	1.08	31860	1.14	33661	1.21	33667	1.21
Total	2792972							

Table 6.3 shows land use change matrix describes the annual rate of land use change during different periods 2001-08, 2008-16 and 2001-16.

Table 6.3: Change Matrix of different LU class - Kerala

Kerala	2001	2008	2016	% change (2001-08)	% change (2008-16)	% change (2001-16)
Forest	1317725	1286647	1262127	-0.34	-0.24	-0.29
Scrub. Veg.	130261	131455	135679	0.13	0.40	0.27
Plantations	1288366	1316574	1334987	0.31	0.17	0.24
Waterbodies	26425	26436	26512	0.01	0.04	0.02
Others	30195	31860	33667	0.77	0.69	0.73
Total	2792972					

The study has revealed there has been a decline of 1.99% of forest cover in the period between 2001 and 2016. During the same period plantations has increased by 1.67%. Table 6.4 describes the percentage change in area of different land use classes in the study period. Fig 6.3 shows the percentage change of area of different land use classes in the study period.

Table 6.4: Percentage change of different LU classes in study period - Kerala

Kerala	**2001-08 (%)**	**2008-16(%)**	**2001-16(%)**
Forest	-1.11	-0.88	-1.99
Scrub. Veg.	0.04	0.15	0.19
Plantations	1.01	0.66	1.67
Waterbodies	0.00	0.00	0.00
Others	0.06	0.06	0.12

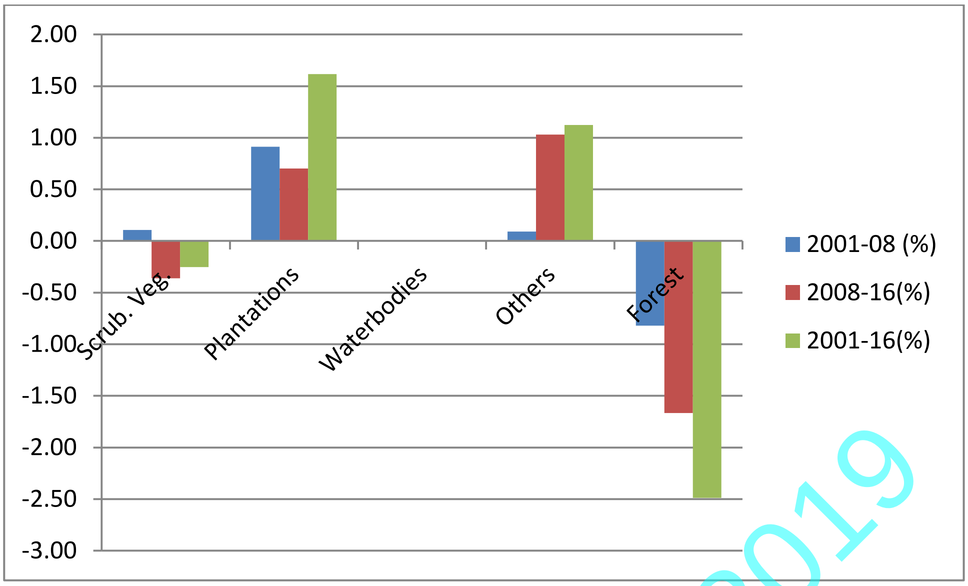


Fig. 6.3: Percentage change of different land use classes in the study period – Kerala.

6.1.2. Time Series MODIS EVI based LU change Analysis from 2001 to 2016 – Tamil Nadu: The hill ranges in South Eastern side of Western Ghats falls in the state of Tamil Nadu. Around 19.09% of the state area comes in the ranges of Western Ghats. Tamil Nadu is dominated by agrarian economy but with the rise in population there has been pressure on land. This has led to change in LU patterns with forest being cleared for plantations, settlements, industries, infrastructure etc. As per the current statistics the state is endowed with only 16.3% (12th Five Year Plan, Tamil Nadu) as compared to the target of 33% forest cover set by Govt. of India. Even though there has been decrease in agricultural land, the productivity has increased tending to maintain the balance. The decrease in forest cover has been a concern of threat and there have been serious afforestation and plantation drives all across the state (State of Environment, FSI, 2015). Commercial crops like rubber, teak, eucalyptus, palm, tea, coffee etc. have been planted in the recent years to maintain a green blanket across the state. Natural calamities like cyclone, flood, forest fire etc. have also led to tremendous loss of forest cover. Fig. 6.4 shows the spatial extent of change in LU during the period 2001 to 2016.

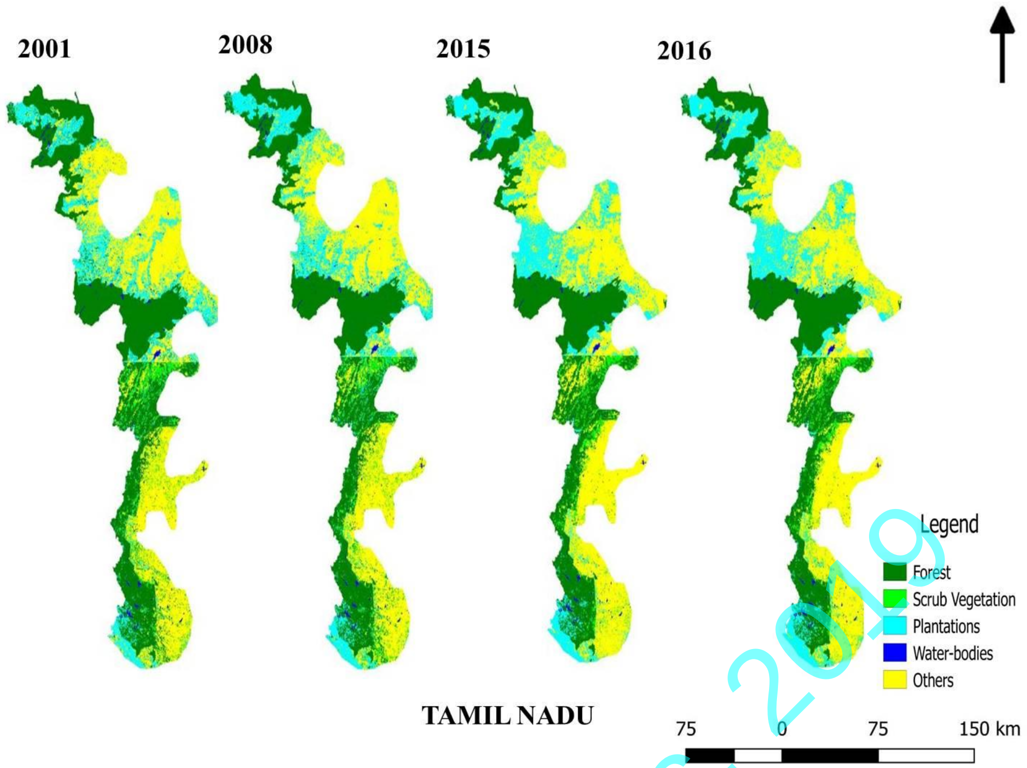


Fig.6.4: Spatial extent of LU changes in Tamil Nadu from 2001 to 2016.

The accuracy of the classified maps has been computed by generating error matrix and the coefficient of kappa ranges from 0.79 to 0.85 for different zones of Tamil Nadu. Table 6.5 shows the area under different land use classes with respect to the total area under study of the state.

Table 6.5: Area under different LU class – Tamil Nadu

Area	**2001**		**2008**		**2015**		**2016**	
Tamil Nadu	**ha**	**%**	**ha**	**%**	**ha**	**%**	**ha**	**%**
Forest	979639	39.46	945721	38.09	891593	35.91	891593	35.91
Scrub Veg.	116761	4.70	113975	4.59	102825	4.14	100623	4.05
Plantations	413679	16.66	440619	17.75	488671	19.68	488671	19.68
Waterbodies	21159	0.85	21216	0.85	21199	0.85	21199	0.85
Others	951538	38.33	961245	38.72	978488	39.41	980690	39.50
Total	2482776							

Table 6.6 shows the annual rate of land use change occurring during different periods 2001-08, 2008-16 and 2001-16.

Table 6.6: Change Matrix of different LU class – Tamil Nadu

Tamil Nadu	2001	2008	2016	% change (2001-08)	% change (2008-16)	% change (2001-16)
Forest	979639	945721	891593	-0.50	-0.74	-0.63
Scrub. Veg.	116761	113975	102825	-0.34	-1.29	-0.85
Plantations	413679	440619	488671	0.90	1.29	1.11
Waterbodies	21159	21216	21199	0.04	-0.01	0.01
Others	951538	961245	978488	0.14	0.22	0.19
Total	2482776					

The study has revealed that there has been an annual decline of 0.63% in forest cover between 2001 and 2016. During the period 2008 – 16 there has been a lot of afforestation drives all across Tamil Nadu, which has been reflected with an annual increase of 1.29% in plantation. Table 6.7 describes the percentage change of each land use category in the study period. The land use change matrix reveals the rate of change of each land use category. The study has revealed about 3.15% of forest cover has been lost between 2001 to 2016 which has been supplemented with the growth of plantations (2.69%) and built – up areas and agricultural lands (0.57%). Fig 6.5 show the percentage change of area in different land use classes in the study period.

Table 6.7: Percentage change of different LU classes in study period – Tamil Nadu

Tamil Nadu	**2001-08 (%)**	**2008-16(%)**	**2001-16(%)**
Forest	-1.21	-1.94	-3.15
Scrub. Veg.	-0.10	-0.40	-0.50
Plantations	0.96	1.72	2.69
Waterbodies	0.00	0.00	0.00
Others	0.35	0.62	0.96

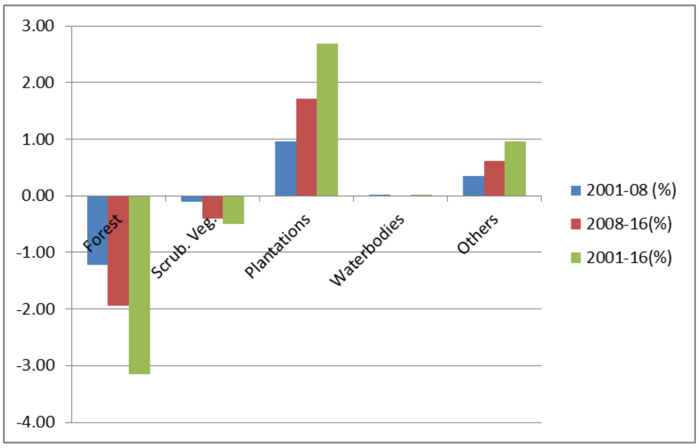


Fig. 6.5: Percentage change of different LU classes in the study period – Tamil Nadu.

6.1.3. Time Series MODIS EVI based LU change Analysis from 2001 to 2016 – Karnataka:

The Sahyadri range runs continuously from North to South in the Western part of the state Karnataka. The state has a lush forest cover which is under threat of degradation through natural and man-made factors. The state has about 22.61% its geographical area under forest (State of Environment, FSI, 2015). Over the last few decades, these forests are threatened due to increased deforestation, rise in commercial plantations, settlements along the forest, construction of dams etc. Around 22% of the geographic area of the state has been part of this study. In the last few years there has been a rampant rise in commercial plantations like teak, acacia, coconut, rubber, eucalyptus etc. leading to the loss of forest cover. Fig. 6.6 shows the spatial extent of LU change in the period from 2001 to 2016.

The accuracy of the classified map has been computed by generating error matrix and the coefficient of kappa ranges from 0.77 to 0.82 for different zones of Karnataka. Table 6.8 shows the area under different land use classes with respect to the total area under study of the state.

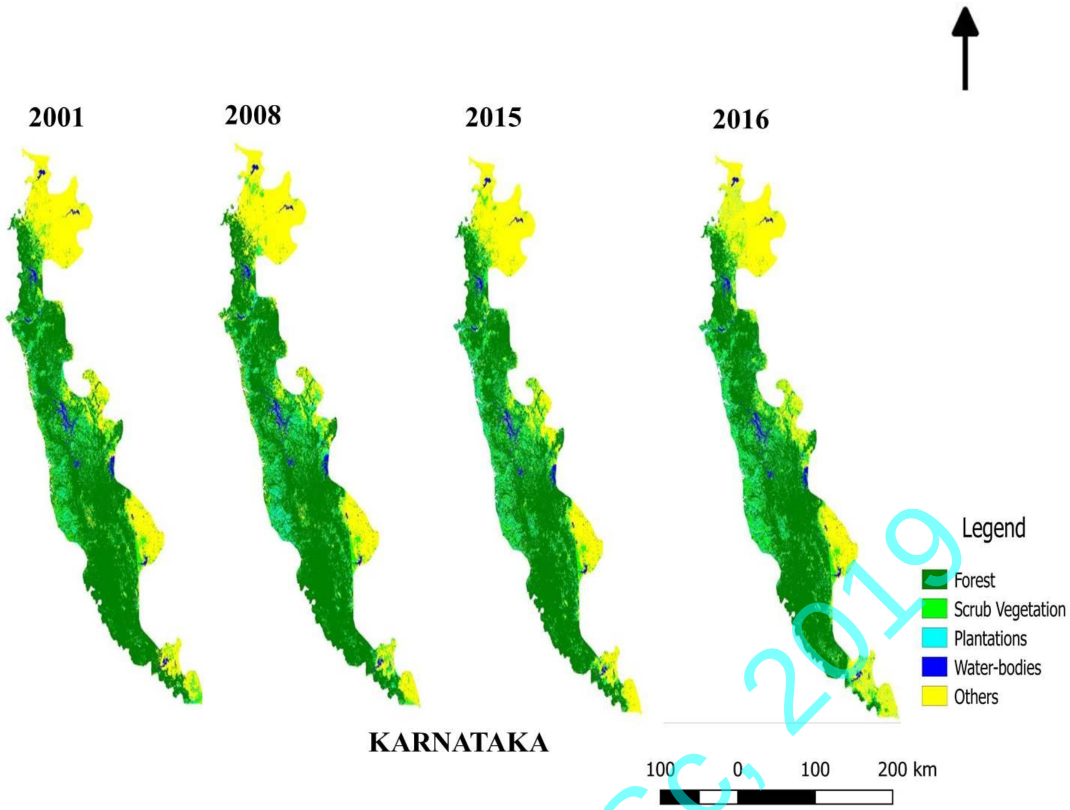


Fig.6.6: Spatial extent of LU changes in Karnataka from 2001 to 2016.

Table 6.8: Area under different LU class – Karnataka

Area	**2001**		**2008**		**2015**		**2016**	
Karnataka	**ha**	**%**	**ha**	**%**	**ha**	**%**	**ha**	**%**
Forest	2424398	57.43	2396084	56.76	2320670	54.97	2265285	53.66
Scrub Veg.	400733	9.49	390933	9.26	402289	9.53	421351	9.98
Plantations	200740	4.76	271438	6.43	302117	7.16	315019	7.46
Waterbodies	81486	1.93	81654	1.93	82968	1.97	81734	1.94
Others	1114238	26.39	1081486	25.62	1113551	26.38	1138206	26.96
Total	4221595							

Table 6.9 shows the annual rate of change in land use at different periods 2001-08, 2008-16 and 2001-16.

Table 6.9: Change Matrix of different LU class – Karnataka

Karnataka	2001	2008	2016	% change (2001-08)	% change (2008-16)	% change (2001-16)
Forest	2424398	2396084	2265285	-0.17	-0.70	-0.45
Scrub. Veg.	400733	390933	421351	-0.35	0.94	0.33
Plantations	200740	271438	315019	4.31	1.86	3.00
Waterbodies	81486	81654	81734	0.03	0.01	0.02
Others	1114238	1081486	1138206	-0.43	0.64	0.00

Total	4221595

The study reveals there has been continuous decline in forest cover with increase in scrub vegetation and plantations which can be attributed to increase in human settlements, commercial plantations. Even though plantations provide a green cover they destroy the structural integrity of the forest. The study shows about 3.77% forest cover has been lost in the period between 2001 and 2016. The loss has been dominating in the regions adjoining coast and plains of Western Ghats in Karnataka. Table 6.10 describes the percentage change of area in each land use classes in the study period. Fig 6.7 shows the percentage change of area under different land use classes in the study period

Table 7.10: Percentage change of different LU classes in study period – Karnataka

Karnataka	2001-08 (%)	2008-16(%)	2001-16(%)
Forest	-0.67	-3.10	-3.77
Scrub. Veg.	-0.23	0.72	0.49
Plantations	1.67	1.03	2.71
Waterbodies	0.00	0.00	0.01
Others	-0.78	1.34	0.57

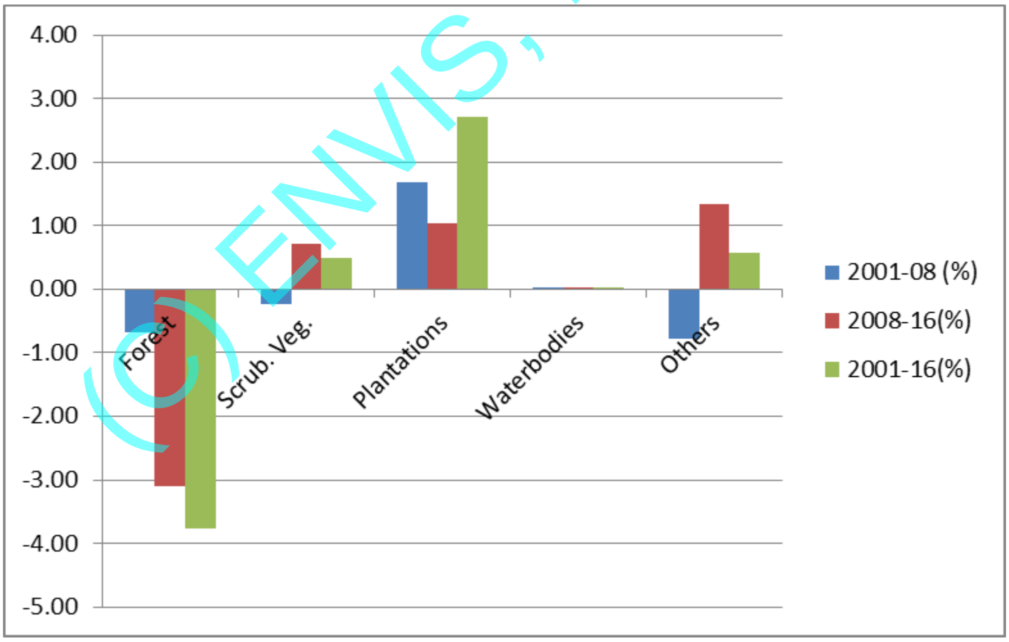


Fig. 6.7: Percentage change of different LU classes in the study period – Karnataka.

7.1.4. Time Series MODIS EVI based LU change Analysis from 2001 to 2016 – Goa: The Western Ghats cover about 50% of the geographic area of Goa. The state has a rich forest cover with 59.94% of its total geographical area under forest (State of Forest Report, FSI, 2015) which satisfies the ecological target of 33% of forest cover set by Govt. of India. The forests of Goa are typical of the vegetation of Western Ghats. Over the recent years, there has been decline in forest cover due to increase in mining, settlements, plantations etc. The plantations in Goa are coconut, teak, spices, acacia, eucalyptus, bamboo etc. Fig. 6.8 shows the spatial extent of land use change from 2001 to 2016. The accuracy of the classified map has been computed by generating error matrix and the coefficient of kappa ranges from 0.79 to 0.82 for different zones of Goa. Table 6.11 shows the area under different land use classes with respect to the total area under study of the state.

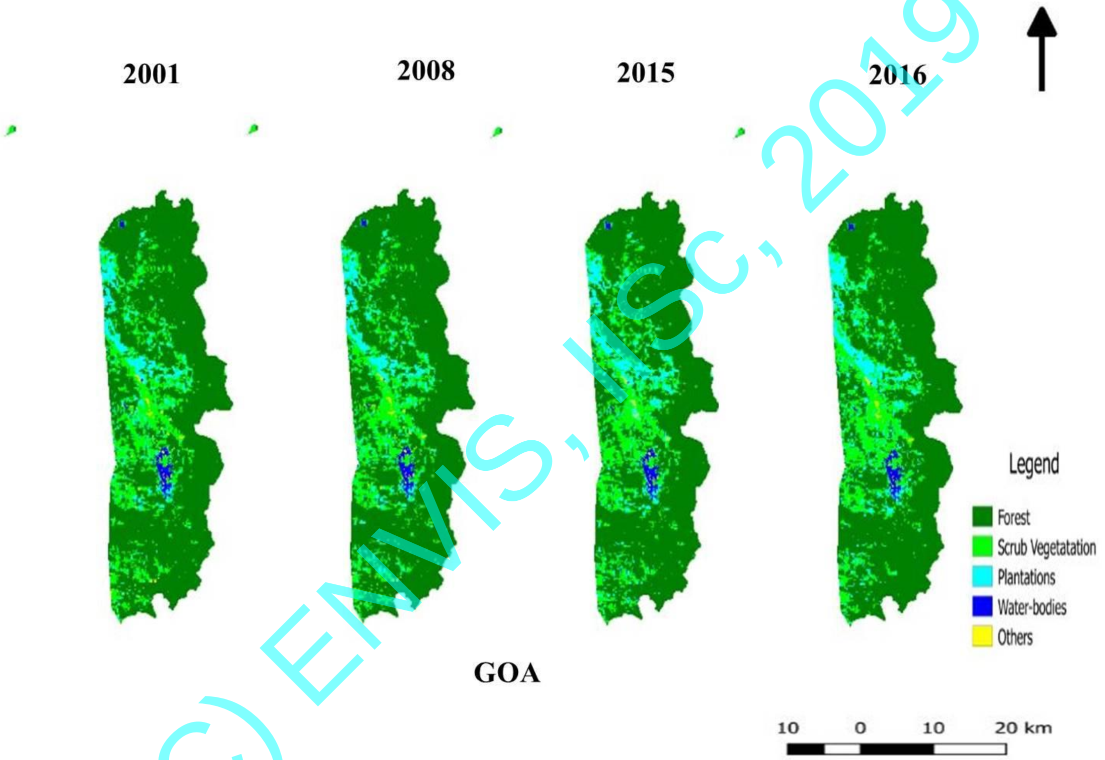


Fig.6.8: Spatial extent of LU changes in Goa from 2001 to 2016.

Table 6.11. Area under different LU class – Goa

Area	2001		2008		2015		2016	
Goa	**ha**	**%**	**ha**	**%**	**ha**	**%**	**ha**	**%**
Forest	137540.54	74.45	137806.79	74.59	136548.72	73.91	134898.62	137540.54
Scrub Veg.	30756.98	16.65	29853.08	16.16	30427.23	16.47	30907.29	30756.98
Plantations	13429.63	7.27	14142.65	7.66	14907.57	8.07	16106.61	13429.63
Waterbodies	1994.20	1.08	1976.82	1.07	1976.82	1.07	1976.82	1994.20
Others	1026.22	0.56	968.23	0.52	887.23	0.48	858.23	1026.22
Total	184747.57							

The annual rate of change of each land use class in different time periods 2001-08, 2008-16 and 2001-16 is shown in Table 6.12. The study reveals that there has been a strenuous rise in forest plantation in the period between 2008 and 2016 at the loss of forest and open spaces. The regions covered with scrub vegetation are also undergoing land use changes at 0.25% annually.

Table 6.12: Change Matrix of different LU class – Goa

Goa	2001	2008	2016	% change (2001-08)	% change (2008-16)	% change (2001-16)
Forest	138540.54	137806.79	134898.62	-0.08	-0.27	-0.18
Scrub. Veg.	29756.98	29853.08	30907.29	0.05	0.43	0.25
Plantations	13429.63	14142.65	16106.61	0.74	1.63	1.21
Waterbodies	1994.2	1976.82	1976.82	-0.13	0.00	-0.06
Others	1026.22	968.23	858.23	-0.83	-1.51	-1.19
	184747.57	184747.57	184747.57			

The study shows about 1.97% of forest cover has been lost between 2001 and 2016. This loss has been identified to have occurred in fringes adjoining settlements, plantations etc. Table 6.13 describes the percentage change in area of each land use classes in the study period. Fig 6.9 shows the percentage change of area under different land use classes in the study period

Table 6.13: Percentage change of different LU classes in study period – Goa

Goa	2001-08 (%)	2008-16(%)	2001-16(%)
Forest	-0.40	-1.57	-1.97
Scrub. Veg.	0.05	0.57	0.62
Plantations	0.39	1.06	1.45
Waterbodies	-0.01	0.00	-0.01
Others	-0.03	-0.06	-0.09

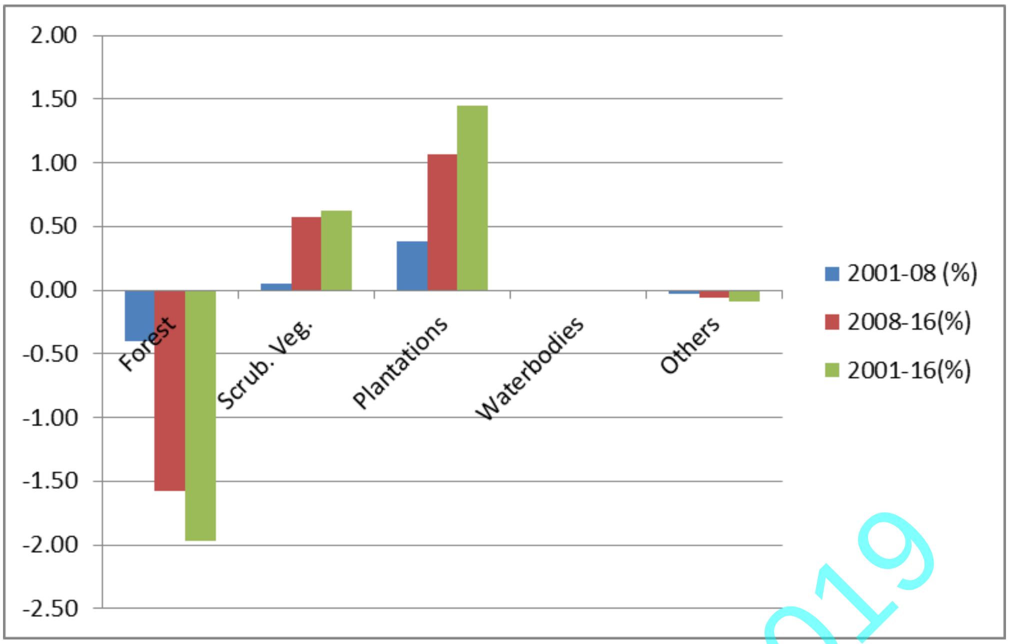


Fig. 6.9 Percentage change of different LU classes in the study period – Goa

6.1.5. Time Series MODIS EVI based LU change Analysis from 2001 to 2016 – Maharashtra: The Western Ghats run about 720 km continuously from North to South of the state making Maharashtra with the longest stretch of continuous range. About 20% of the geographic area of the state comes under the purview of this study. The forest cover of the state is estimated to be around 16.45% (State of Environment, FSI, 2015) which is estimated to have increased over the recent years. This can be attributed to rise in commercial plantation like eucalyptus, bamboo, acacia etc. Fig. 6.12 shows the spatial extent of changes in land use from 2001 to 2016. The accuracy of the classified map has been computed by generating error matrix and the coefficient of kappa ranges from 0.80 to 0.84 for different zones of Maharashtra. Table 6.14 shows the area under different land use classes with respect to the total area under study of the state.

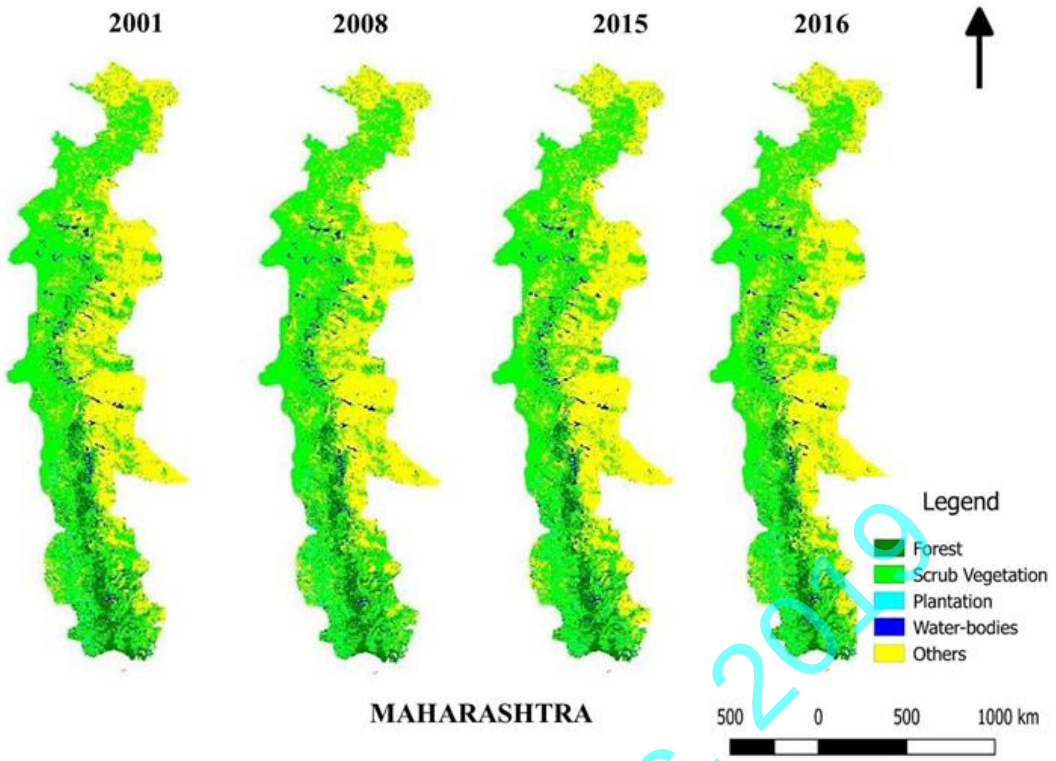


Fig.6.10: Spatial extent of LU changes in Maharashtra from 2001 to 2016

Table 6.14 Area under different LU class – Maharashtra

Area	**2001**		**2008**		**2015**		**2016**	
Maharashtra	**ha**	**%**	**ha**	**%**	**ha**	**%**	**ha**	**%**
Forest	602101	10.44	563789	9.77	510233	8.85	509186	8.83
Scrub Veg.	2749055	47.66	2782991	48.25	2705363	46.90	2706069	46.91
Plantations	82245	1.43	86307	1.50	99101	1.72	96559	1.67
Waterbodies	97516	1.69	97499	1.69	97612	1.69	97521	1.69
Others	2237406	38.79	2237737	38.79	2356014	40.84	2358988	40.90
Total	5768323							

The annual rate of change of each land use class in different time periods 2001-08, 2008-16 and 2001-16 is shown in Table 6.15. Even though dense evergreen forest cover is comparatively less in this region, the region has a rich deciduous forest cover which is declining at the rate of 1.12%. The study reveals that there has been a tremendous increase plantation in the period between 2008 and 2016. The regions covered with scrub vegetation are also undergoing land use change at the rate of 0.11% due to tremendous pressure from commercial plantation; agricultural farms etc. at the rate of 0.35% annually.

Table 6.15: Change Matrix of different LU class – Maharashtra

Maharashtra	2001	2008	2016	% change (2001-08)	% change (2008-16)	% change (2001-16)
Forest	602101	563789	509186	-0.94	-1.27	-1.12
Scrub. Veg.	2749055	2782991	2706069	0.18	-0.35	-0.11
Plantations	82245	86307	96559	0.69	1.40	1.07
Waterbodies	97516	97499	97521	0.00	0.00	0.00
Others	2237406	2237737	2358988	0.00	0.66	0.35
	5768323					

The percentage change in area of each land use class in the study period is described in Table 6.16. There has been a loss of about 1.61% of forest cover between 2001 and 2016 which has been highest when compared with other land use classes. There has been an increase of 0.25% in plantations between the period 2001 and 2016. Even though the region has been facing severe crop loss, there has been rise in agricultural class (Others) which has been attributed to the rise in cultivation of cereals, horticulture, cotton, vegetables, fruits etc. Fig. 6.12 shows the percentage change of area under different land use classes in the study period**.**

Table 6.16: Percentage change of different LU classes in study period – Maharashtra

Maharashtra	2001-08 (%)	2008-16(%)	2001-16(%)
Forest	-0.66	-0.95	-1.61
Scrub. Veg.	0.59	-1.33	-0.75
Plantations	0.07	0.18	0.25
Waterbodies	0.00	0.00	0.00
Others	0.01	2.10	2.11

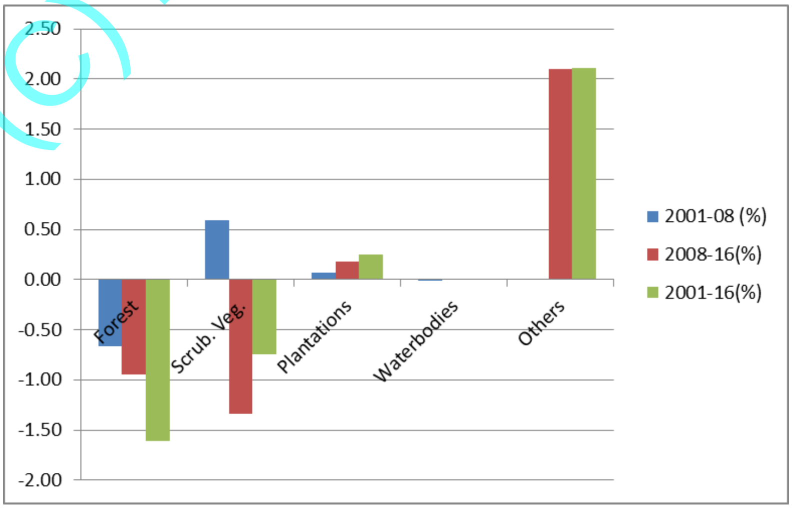


Fig. 6.11: Percentage change of different LU classes in the study period – Maharashtra

6.1.6. Time Series MODIS EVI based LU change Analysis from 2001 to 2016 – Gujarat:

The Western Ghats cover about 2% of the geographic area of the State. This region is dominated with open forests and scrub vegetation. Dense forest cover types like evergreen, moist deciduous etc. are not found in this region. The forest cover of this region is estimated to be around 11.46% to the total geographic area of the state which falls well below the ecological target of 33% forest cover as set by the Govt. of India. Fig. 6.13 shows the spatial extent of change in land use from 2001 to 2016.

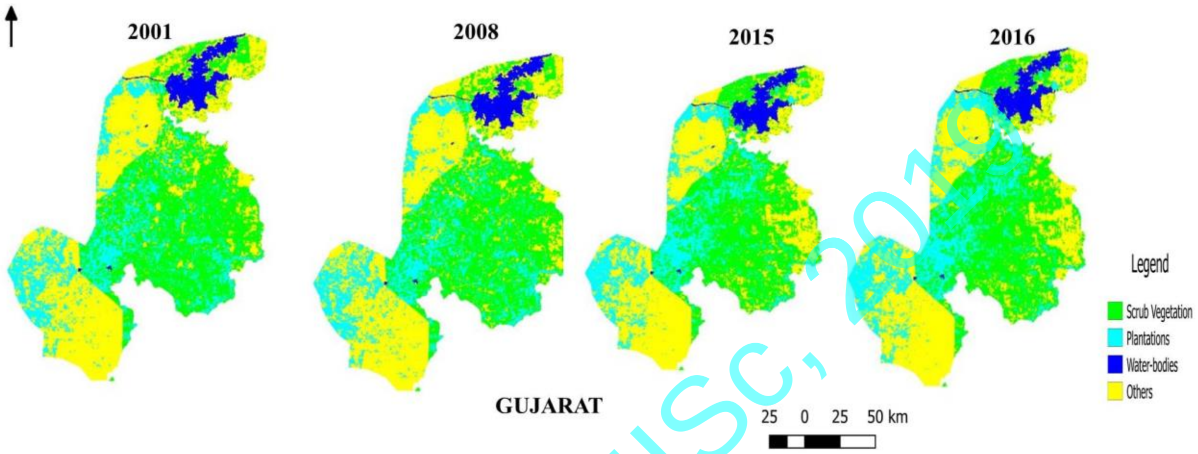


Fig.6.12: Spatial extent of LU changes in Gujarat from 2001 to 2016.

The accuracy of the classified map has been computed by generating error matrix and the coefficient of kappa ranges from 0.83 to 0.87 for different zones of Gujarat. Table 6.17 shows the area under different land use classes with respect to the total area under study of the state.

Table 6.17: Area under different LU class – Gujarat

Area	**2001**		**2008**		**2015**		**2016**	
Gujarat	**ha**	**%**	**ha**	**%**	**ha**	**%**	**ha**	**%**
Scrub Veg.	210272.39	37.75	205811.33	36.95	200377.78	35.98	200377.78	35.98
Plantations	111486.56	20.02	115747.02	20.78	117418.23	21.08	117418.23	21.08
Waterbodies	26834.35	4.82	26828.75	4.82	26823.14	4.82	26823.14	4.82
Others	208355.97	37.41	208562.17	37.45	212330.12	38.12	212330.12	38.12
Total	556949.27							

The study reveals an increase in area under plantations and agriculture. The annual rate of change of each land use class in different time periods 2001-08, 2008-16 and 2001-16 is shown in Table 6.18. The annual rate of increase of Others class is around 0.22% which has been attributed to the rise in horticulture, fruits (grape, pomegranate), jatropa etc. The region is facing a rise in cultivation of plantation crops like bamboo, date palm, eucalyptus etc. which has been identified with increase in area under plantation.

Table 6.18: Change Matrix of different LU class – Gujarat

Gujarat	2001	2008	2016	% change (2001-08)	% change (2008-16)	% change (2001-16)
Scrub. Veg.	210272.39	205811.33	200377.78	-0.31	-0.33	-0.32
Plantations	111486.56	115747.02	117418.23	0.54	0.18	0.35
Waterbodies	26834.34	26828.75	26823.14	0.00	0.00	0.00
Others	208355.98	208562.17	212330.12	0.01	0.22	0.13
Total	556949.27					

Table 6.19 describes the percentage change in area of each land use class during the study period.

Table 6.19: Percentage change of different LU classes in study period – Gujarat

Gujarat	**2001-08 (%)**	**2008-16 (%)**	**2001-16(%)**
Scrub. Veg.	-0.80	-0.98	-1.78
Plantations	0.76	0.30	1.07
Waterbodies	0.00	0.00	0.00
Others	0.04	0.68	0.71

The study has revealed a decline of 1.78% of scrub vegetation in the period from 2001 to 2016. The spatial maps reveal increase in plantation has occurred by clearing of forest. Fig. 6.14 shows the percentage change in area of different land use class in the study period.

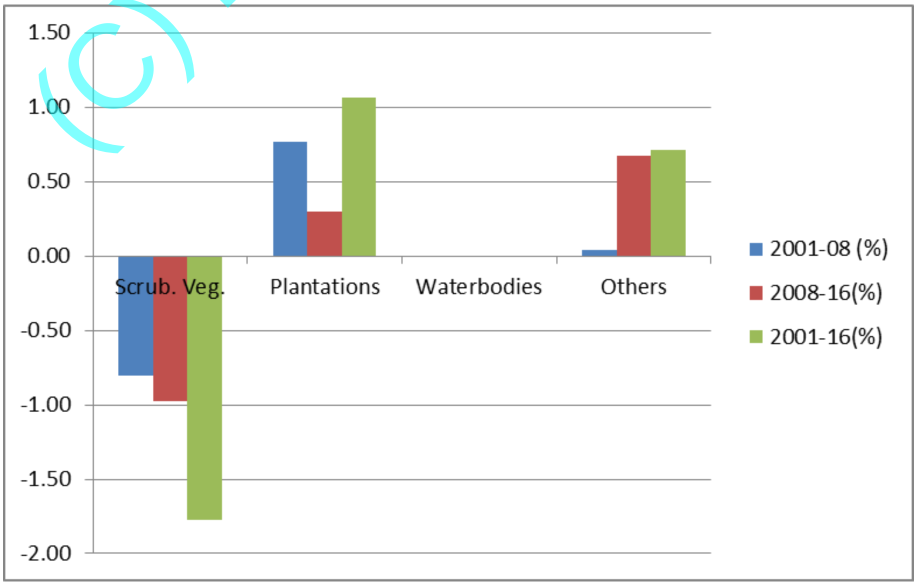


Fig. 6.13: Percentage change of different LU classes in the study period – Gujarat

6.1.7. Time Series MODIS EVI based LU change Analysis from 2001 to 2016 – Western Ghats: The land use of Western Ghats is compiled by aggregating the land use maps based on the agro-climatic and administrative boundaries. There have been scenarios where confusions are found to exist between different land use classes which eventually led the analysis to be carried out on a smaller scale. The confusions existing during analysis have been overcome by carrying out multiple clustering and reclassification of the image. Fig. 6.14 shows the spatial extent of land use change in Western Ghats between 2001 and 2016. Table 6.20 describes the area under different land use classes with respect to the total area under study. It may be noted there has been decrease in area under forest which indicates there is a decline in forest. The forest loss can be attributed to rise in plantation, agricultural farms, settlements etc.

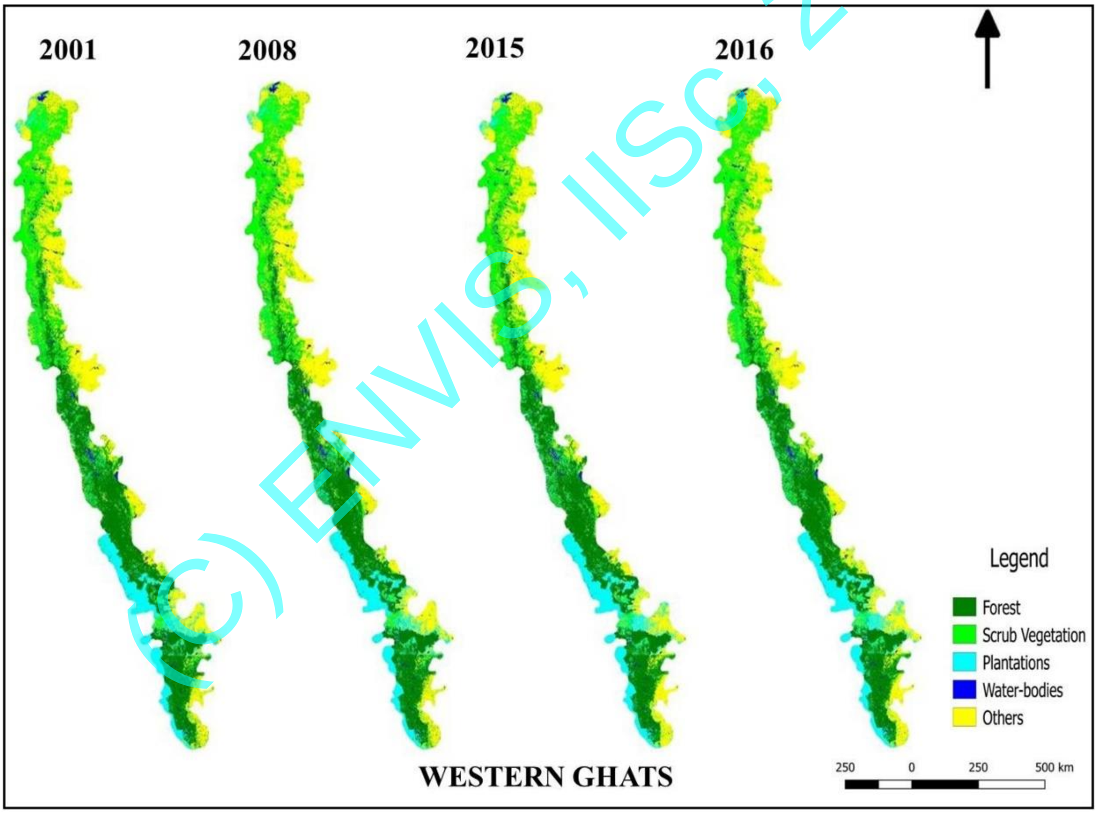


Fig.6.14: Spatial extent of LU changes in Western Ghats from 2001 to 2016

Table 6.21 describes the annual rate of change of each land use class. The annual rate of decline of forest is 0.5% in the period between 2001 and 2016. During the same period the annual rate of increase in plantation is 0.77% in the entire Western Ghats. There has also been annual increase of 0.29% in Others class, which signifies the increase in area under built up, agricultural farms etc.

Table 6.20 Area under different LU class – Western Ghats

Area	**2001**		**2008**		**2015**		**2016**	
Western Ghats	**ha**	**%**	**ha**	**%**	**ha**	**%**	**ha**	**%**
Forest	5461403.54	34.12	5330047.79	33.30	5122835.72	32.00	5063089.62	31.63
Scrub Veg.	3637839.37	22.73	3655018.41	22.83	3576141.01	22.34	3597209.07	22.47
Plantations	2109946.19	13.18	2244827.67	14.02	2356451.8	14.72	2368760.84	14.80
Waterbodies	255414.55	1.60	255610.57	1.60	257002.96	1.61	255783.96	1.60
Others	4542759.19	28.38	4568906.8	28.54	4694931.35	29.33	4722537.35	29.50
Total	16007362.84							

Table 6.21: Change Matrix of different LU class – Western Ghats.

Western Ghats LU	2001	2008	2016	% change (2001-08)	% change (2008-16)	% change (2001-16)
Forest	5461403.54	5330047.79	5063089.62	-0.35	-0.64	-0.50
Scrub. Veg.	3637839.37	3655018.41	3597209.07	0.07	-0.20	-0.07
Plantations	2109946.19	2256168.67	2368760.84	0.96	0.61	0.77
Waterbodies	255414.55	255610.57	255783.96	0.01	0.01	0.01
Others	4542759.19	4557565.8	4722537.35	0.05	0.44	0.26
Total	16007362.84					

The percentage change in each land use during the study period is described in Table 6.22. The study reveals about 1.61% forest cover has been lost in the period 2001-16. Even though there has been increase of 0.59% of scrub vegetation in the period 2001-08, there has been a tremendous decline of about 1.33% in the period 2008-16. This has been attributed with scrub vegetation being turned into agricultural farms, settlements i.e. Others class. The study also reveals the entire belt of Western Ghats is under tremendous pressure due to increasing population, changing land use. There has not been any significant change in water-bodies.

Table 6.22: Percentage change of different LU classes in study period – Western Ghats

Western Ghats	**2001-08 (%)**	**2008-16(%)**	**2001-16(%)**
Forest	-0.82	-1.67	-2.49
Scrub. Veg.	0.11	-0.36	-0.25

Plantations	0.91	0.70	1.62
Waterbodies	0.00	0.00	0.00
Others	0.09	1.03	1.12

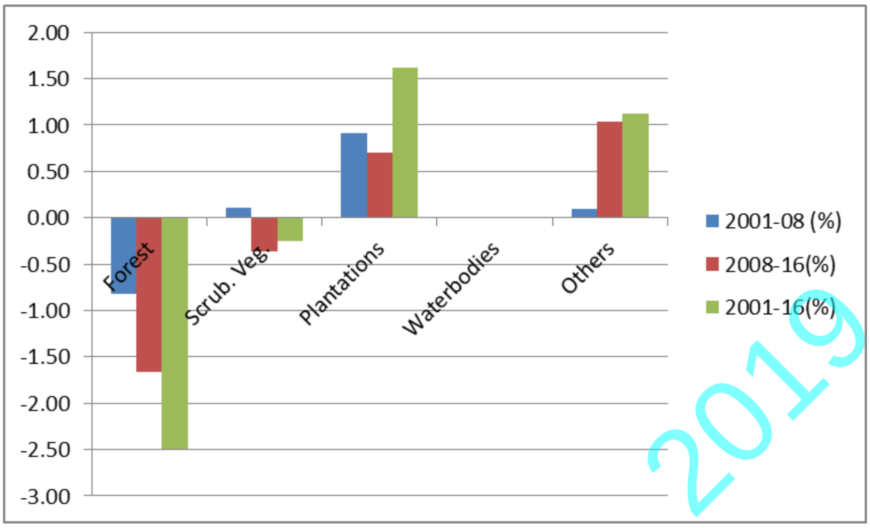


Fig. 6.15: Percentage change of different LU classes in the study period – Western Ghats.

6.2. Spatio temporal LST Analysis: The temperature maps have been prepared from remote sensed images of LST data. Detailed documentation regarding compositing, preparation of data is available in NASA MODIS website. (MODIS 1999)

6.2.1. Time Series MODIS LST based LST change Analysis from 2001 to 2016 – Western Ghats: LST is a crucial variable for environment and climate studies. This section describes the temporal dynamics of land surface temperature. The study has revealed an increase in mean temperature over the entire study area. Fig. 6.16 shows the temporal dynamics of Land Surface Temperature from 2001 to 2016. The study reveals LST values directly dependent on vegetation cover. The regions with thick vegetation cover like the states of Kerala, Karnataka, and Goa show a relatively lesser LST when compared with states like Gujarat, Tamil Nadu where vegetation cover is sparse. It has also been observed that LST varies with land use of the region i.e. water-bodies exhibit a lower LST during day time and a higher LST is observed in 'Others' class (i.e. built up, open spaces). There have been prominent differences in LST between different vegetation classes i.e. plantations and forest with plantations showing a relatively higher temperature than forest cover. The coast of Kerala dominated with plantations as depicted in land use map (Fig. 6.16) shows a relatively higher temperature than the hills of the same region which found to be similar in other regions of the study area. The plains of the study area show a relatively higher temperature when compared with coast and hills which may be attributed to the presence of open spaces and agricultural farms. The coastal side of Western Ghats show a relatively lesser temperature due to presence of sea (Ado., 1992).

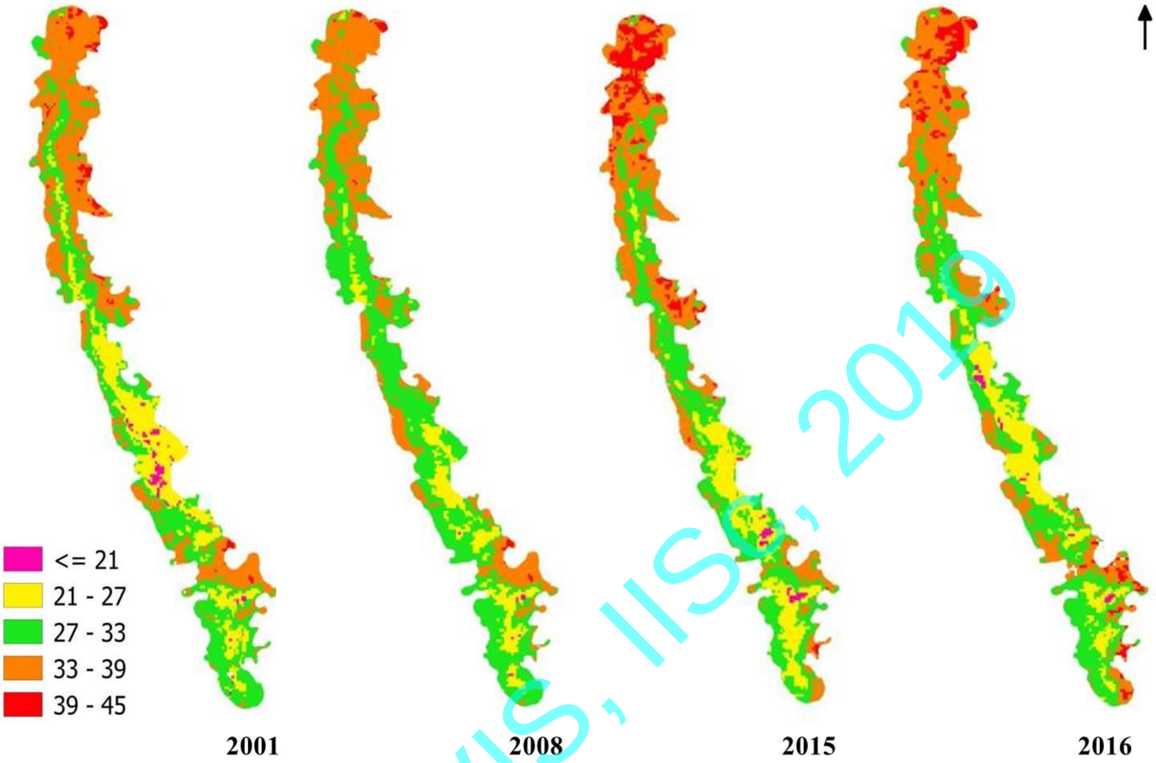


Fig. 6.16: Temporal dynamics of LST from 2001 to 2016.

6.2.2. Validation of LST with Ground data: The LST values have been compared and validated with ground data obtained from NASA climatology grid. The validation has been carried out by taking 13 representative locations all across the study area. The places taken up for validation are shown in Fig. 6.17.

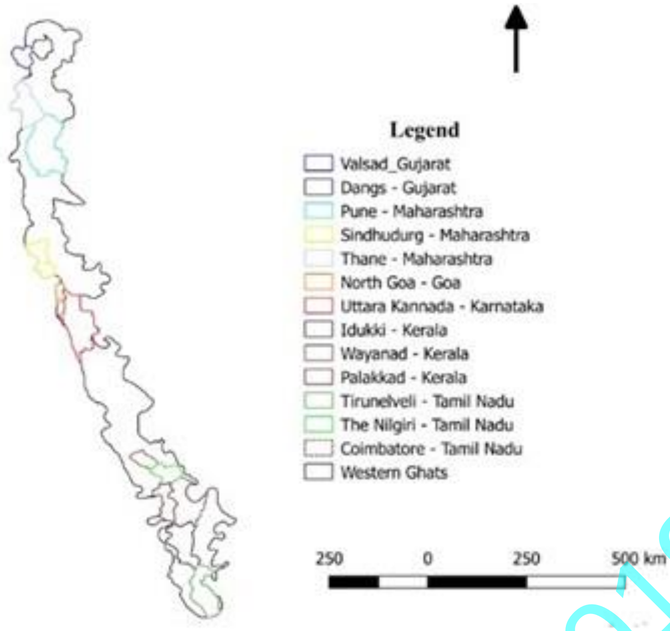
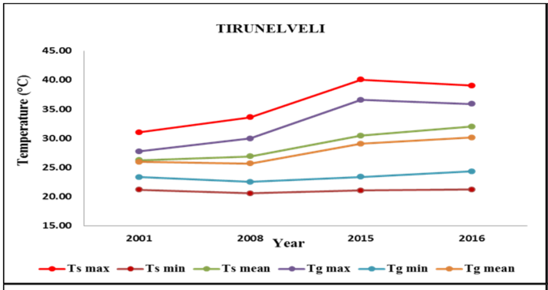
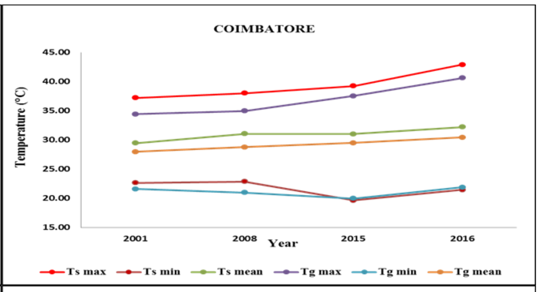
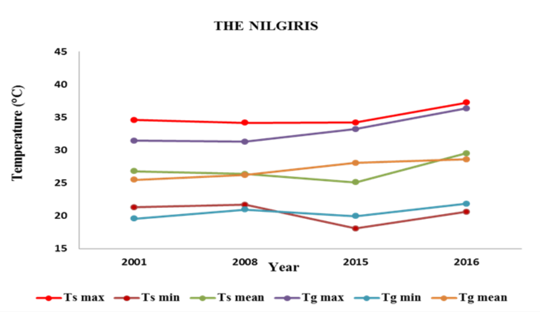


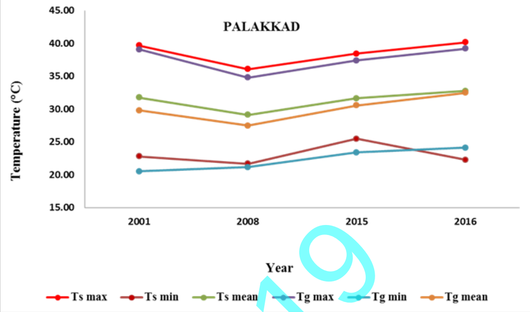
Fig. 6.17: Map showing regions taken up for LST validation

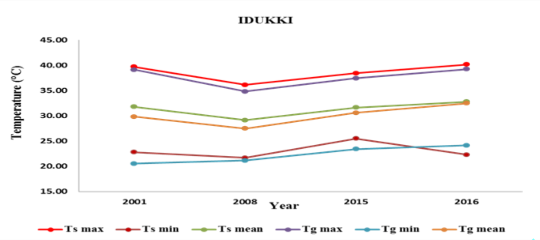
The maximum, minimum and mean temperature of satellite data is compared with maximum, minimum and mean temperature of ground data. The ground data is the air temperature of the region at a height of 2m from ground, whereas satellite data gives the land surface temperature. The LST of MODIS during day time is of 2 to 3°C is higher than the air temperature and at night time vice versa (Colombi et. al., 2007). Fig. 6.18 shows the comparison between ground temperature and satellite temperature.

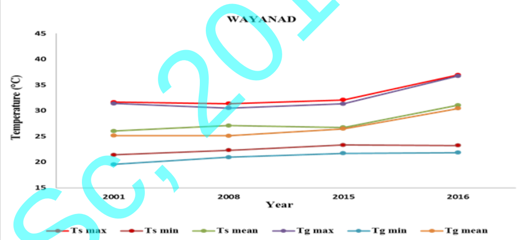


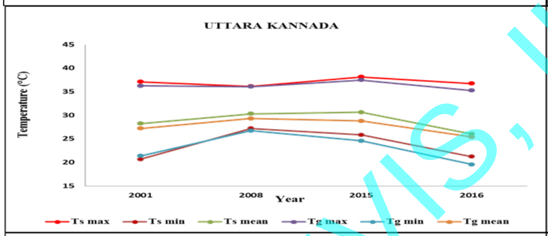


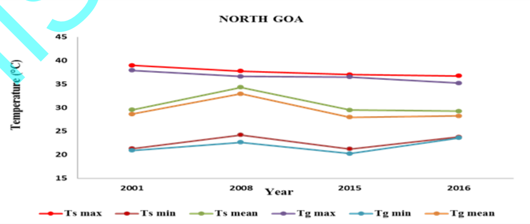


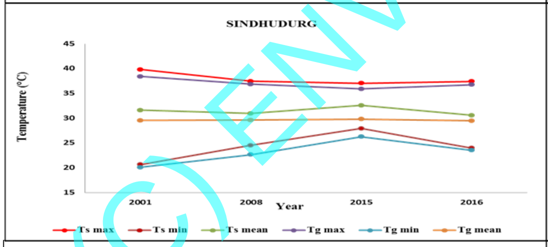


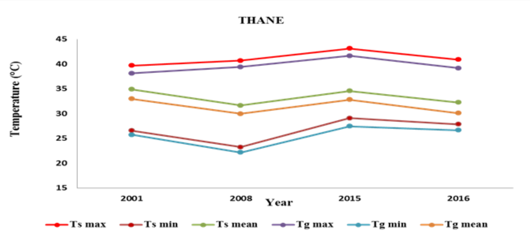


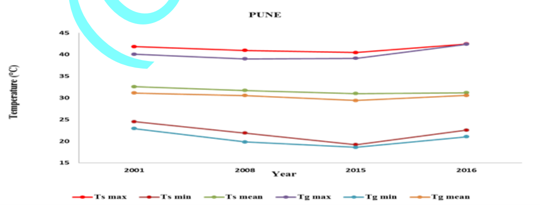


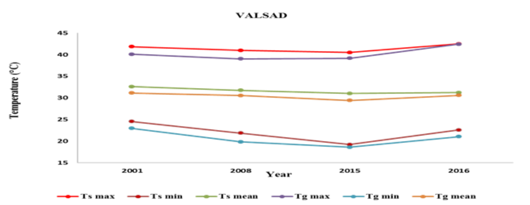


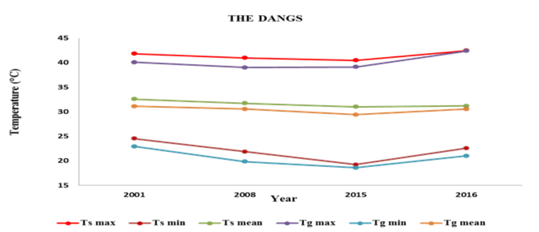












Ts max – Satellite Maximum Temperature
Ts min – Satellite Minimum Temperature
Ts mean – Satellite Mean Temperature
Tg max – Ground Maximum Temperature
Tg min – Ground Minimum Temperature
Tg mean – Ground Mean Temperature

Fig. 6.18: Comparison of max, min and mean temperature from satellite and ground data.

6.3. STATISTICAL ANALYSIS:

6.3.1. COEFFICIENT OF CORRELATION (r):

A coefficient of correlation is a statistical measure to quantify relationship and dependence between two variables (Schielzeth, 2010). The coefficient of correlation lies between -1 and 1. If a positive relationship exists between the variables, the coefficient is 1 and in a negative relationship, the coefficient is -1.

$$r = \frac{N\sum xy - (\sum x)\,(\sum y)}{\sqrt{\left[N\sum x^2 - (\sum x)^2\right]\left[N\sum y^2 - (\sum y)^2\right]}}$$

A coefficient of correlation (r) of 0.8 to 1 indicates a very strong relationship, 0.6 to 0.8 indicates a strong relationship, 0.4 to 0.59 indicates a substantial relationship and 0 to 0.4 negligible or low relationship. In this study, the coefficient of correlation is determined between rate of change in forest, rate of change in agriculture, built up and change in temperature. Table 6.23 describes the relationship between different variables and the coefficient of correlation.

Table 6.23: Relationship between different variables and Pearson's coefficient of correlation

Period	x	y	Relationship	R^2	r	Significance level
2001-08	Rate of change in Forest	Change in Temperature	$y=0.0063x^2 +0.0.214x + 0.2783$	0.69	-0.83	0.05
	Rate of change in Agriculture, built up	Change in Temperature	$y=0.0011 - 0.0179x+0.3514$	0.39	0.63	0.05
2008-16	Rate of change in Forest	Change in Temperature	$y=-0.0107x^2-0.2652x-0.0922$	0.52	-0.72	0.05

	Rate of change in Agriculture, built up	Change in Temperature	$y=-0.00002x^2+0.191x+0.3508$	0.37	0.61	0.05
2001-16	Rate of change in Forest	Change in Temperature	$y=0021x^2+0.2836x+1.9491$	0.61	-0.78	0.05
	Rate of change in Agriculture, built up	Change in Temperature	$y=0.0029x^2-0.1338x+2.5661$	0.60	0.77	0.05

Relationship between rate of change in forest cover and change in temperature: The study has shown forest cover has a direct impact on the temperature of the surroundings. During the period 2001 to 2008, there has been a decline in forest by about 0.82% and in 2008-16 the decline in forest cover has been 1.67%. The study between rate of change in forest cover and change in temperature has shown a strong correlation of 0.83, 0.72 and 0.78 between the variables indicating declining forest cover has direct relationship with increase in temperature of the region. Fig. 6.19 shows the plot between rate of change in forest and change in temperature. The rate of change in forest cover and change in temperature show a second order polynomial relationship across all the locations of Western Ghats which indicates decline in forest, increases the temperature.

Relationship between %change in agricultural land, built-up and change in temperature: The study has shown an increase in built up and agricultural land has direct impact on rise in temperature. During the period 2001-08, the rise in agricultural and built-up was only 0.09% whereas in the period 2008-16, the rise had been 1.03% indicating a huge area of the land has been converted to built-up and agricultural farms. The coefficient of correlation for the periods has shown a positive relationship indicating rise in agricultural lands and built-up rises the temperature of the region. The rate of increase in built up and agricultural lands have shown a second order polynomial relationship across all the locations of Western Ghats indicating the increase in built up and agricultural lands, increases the temperature.

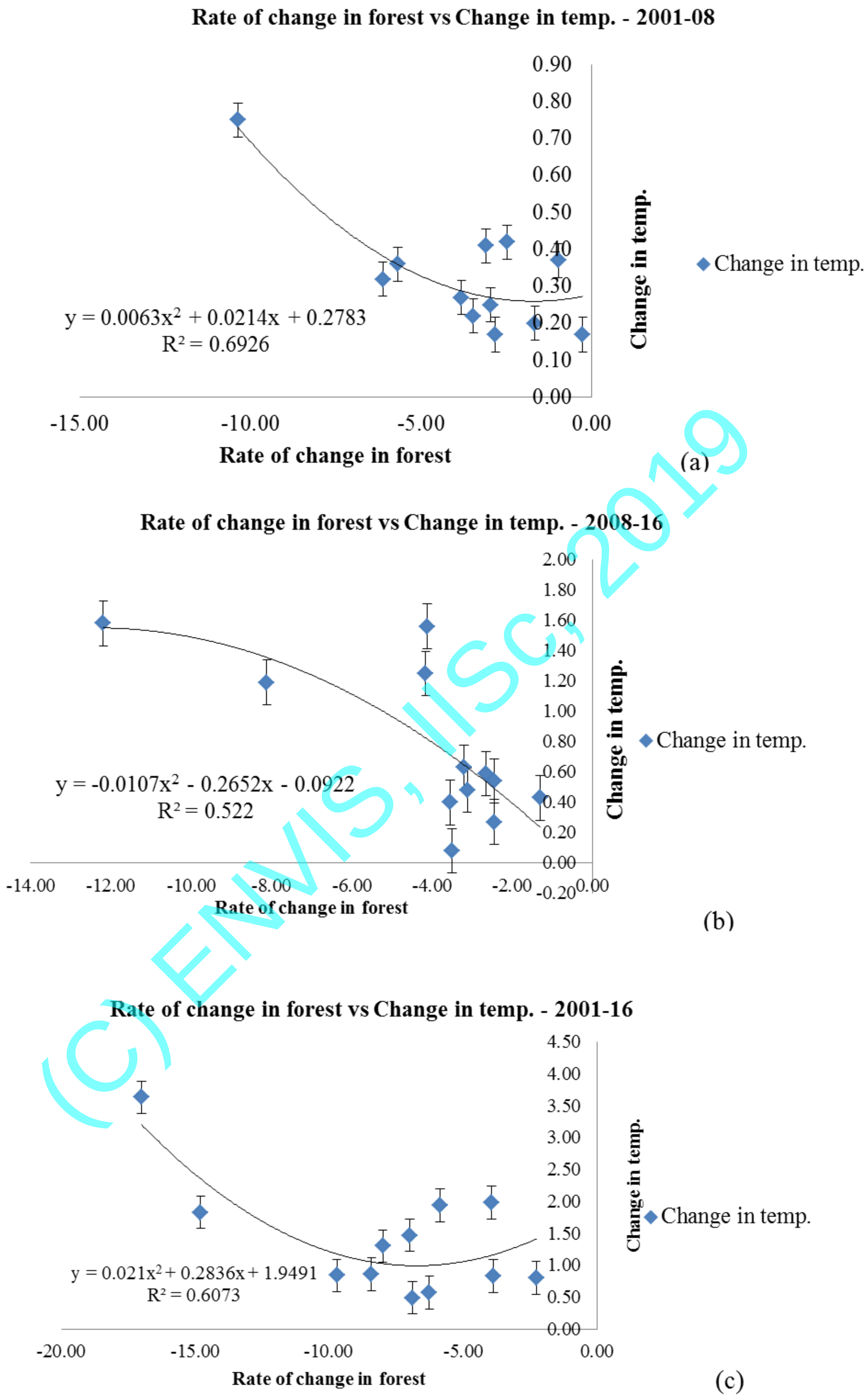


Fig. 6.19: Correlation between rate of change in forest and change in temperature (a) 2001-08 (b)2008-16 (c) 2001-16

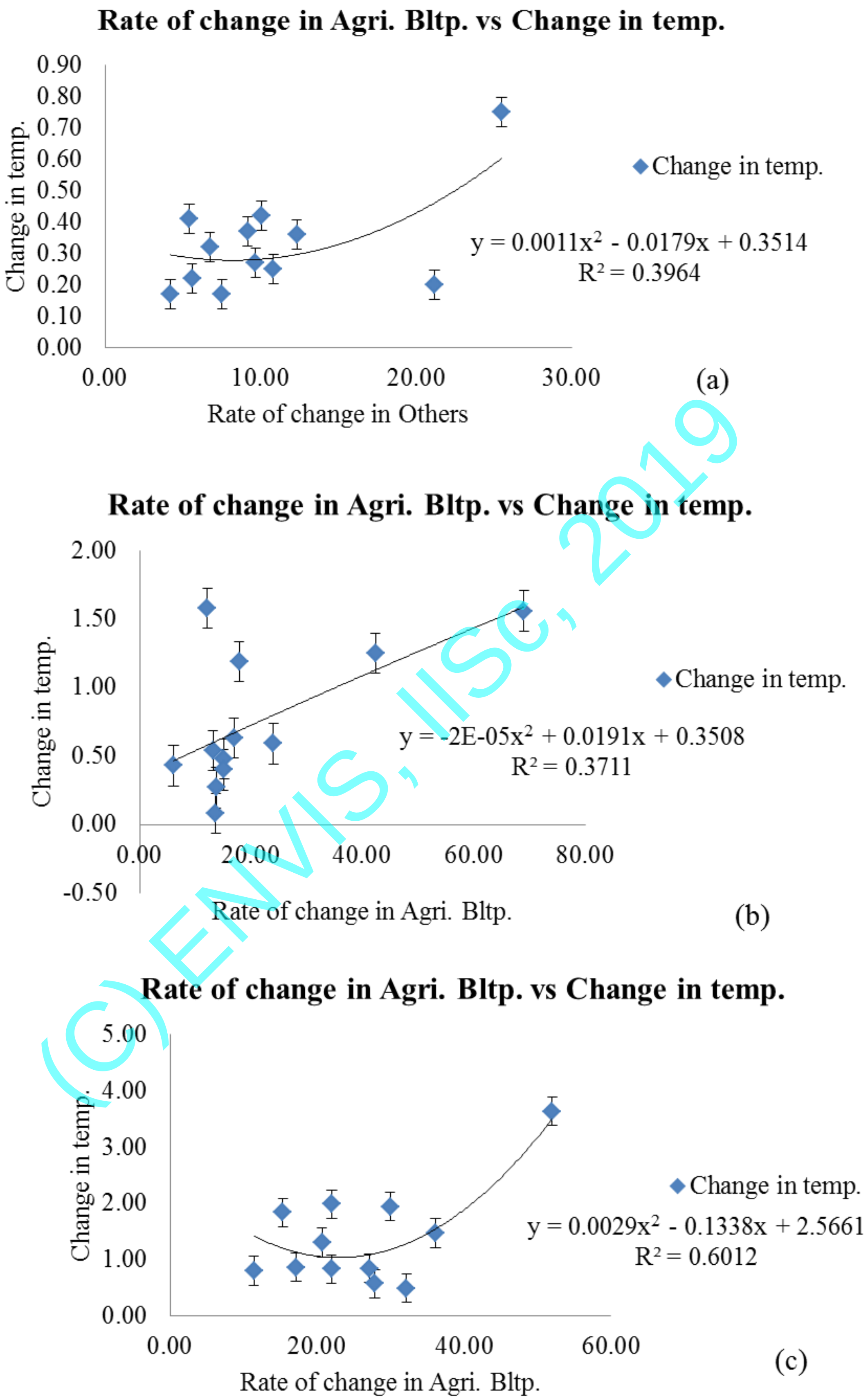


Fig. 6.20: Correlation between rate of change in Agri., bltp. vs change in temp.

(a) 2001-08 (b) 2008-16 (c)2001-16

6.3.2. Multiple Variable Analyses:

Stepwise regression of multi variables were carried out to find out the probable relationship of LST with different independent variables (changes in LU categories). The dependent variable in this study is the change in temperature which is dependent on change in forest cover, agricultural farms and built up areas. The multiple variable analyses helps in understanding the overall phenomena through statistical modelling of the relative contribution of each of the variables to the process. This is usually done by modelling the present rate of changes to understand the dynamics of change and simulate for future.

In this study, the variables are rate of change in forest cover (x_1) and rate of change in agriculture and built-up(x_2) have been modelled to understand the change of temperature (y) for the periods: 2001-08, 2008-16 and 2001-16.

The analysis of the variables have shown a high degree of relationship between rate of change in forest cover, rate of change in built up and agricultural etc. with the changes in temperature (LST). The multiple variable analyses have shown strong correlation during different periods of study. For the study period 2001 to 2008, it shows a correlation of 0.79 indicating a strong relationship between the variables. This shows that decline in the forest cover and increase in built-up and agricultural areas have a direct effect on the rise of temperature. In the period 2008-16, the correlation is 0.71, indicating a strong relationship between the variables. The year 2016 was hottest year of the century, which eventually led to higher rise in temperature values than predicted. This has led to reducing the relationship indicating there could be other parameters associated with rise in temperature other than changing land use. Even though there could be other parameters for increase of temperature in the region, the dominant factors are reduction in forest cover and increase in area under built-up and settlements. The period 2001-16 has an overall correlation of 0.71 indicating a strong relationship between the dependents and independents. The relationship between the variables has been formulated into an equation, to understand the dynamics of the period. Table 6.24 describes the variables and the relationship between them.

Table 6.24: Multiple Variable analyses and Pearson's coefficient of correlation

Period	y=T	x_1	x_2	Probable Relationship	R^2	r	Significance level

2001-08	Change in temperature	Rate of change in forest cover	Rate of change in Agri. & Built up.	T = 0.122-0.036 (rate of change in forest cover)+0.006 (rate of change of others)	0.61	0.79	0.05
2008-16	Change in temperature	Rate of change in forest cover	Rate of change in Agri. & Built up.	T = 0.0707-0.048 (rate of change in forest cover)+0.0211 (rate of change of others)	0.51	0.71	0.05
2001-16	Change in temperature	Rate of change in forest cover	Rate of change in Agri. & Built up.	T = -0.01390-0.091 (rate of change in forest cover)+0.0306 (rate of change of others)	0.50	0.71	0.05

7. CONCLUSION:

Western Ghats (WG) is a unique biodiversity hotspot supporting humankind with abundant resources. The current study has investigated LU changes and the rate of change of WG during 2001-2016. The temporal LST quantification helped to understand the role of biophysical variables changes through LU impact temperature. LU analysis highlighted large scale conversion of natural forests with commercial plantations, agricultural farms, settlements etc. Around 2.5% of natural forest has been lost from 2001 and 2016. The study revealed a large scale conversion of natural forest into plantation in Kerala with the area under plantation higher than area under forest. A similar trend has been observed in Goa post 2008 with forests being cleared for commercial plantations. A stable forest cover is found in many parts of Karnataka with a trend in rise of commercial plantation. Even though reports state there is rise in forest cover of Tamil Nadu, the study reveals this has been attributed to rise in plantations. Even though the states Gujarat and Maharashtra have lesser area under closed forest, a large scale conversion of land to commercial plantation for timber, paper, dying industry etc. is taking place. The LST at temporal scale revealed changes in micro climate of WG due to deforestation and increase in built up and agricultural area which revealed a rise in mean surface temperature. The relationship of LU change with LST has been modelled using multiple regression methods. The current analysis might help decision makers and planners

ANNEXURE

(a) Error Matrix:

The accuracy of the classified map has been verified through computation of error matrix and calculation of the coefficient of kappa. The value of coefficient of kappa for the classified maps has been greater than 0.77 for all the regions. As the study involved a large number of land use maps being prepared, the error matrix depicting 2 regions has been put up here.

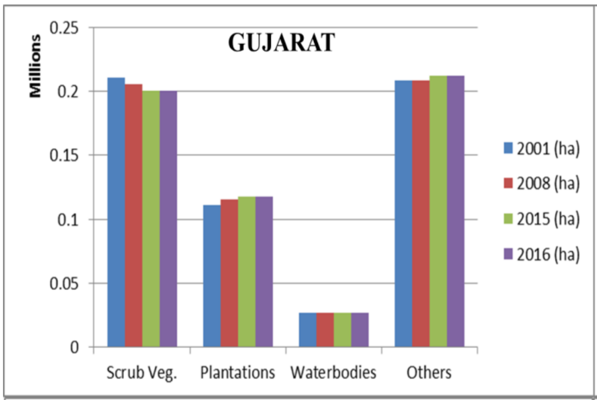
CLASSIFIED IMAGE	2016	REFERENCE IMAGE						
	Karnataka Hills	Forest	Scrub Veg.	Plantation	Water bodies	Others	Total	User's Accuracy
	Forest	29	0	1	0	0	30	0.96
	Scrub Veg.	0	7	0	0	2	9	0.78
	Plantation	3	1	8	0	0	12	0.67
	Waterbodies	0	0	0	10	0	10	1
	Others	0	2	0	0	9	11	0.82
	Total	32	10	9	10	11	72	0
	Producer's Accuracy	0.90	0.7	0.88	1	0.81	0	0.87
	Kappa							0.82

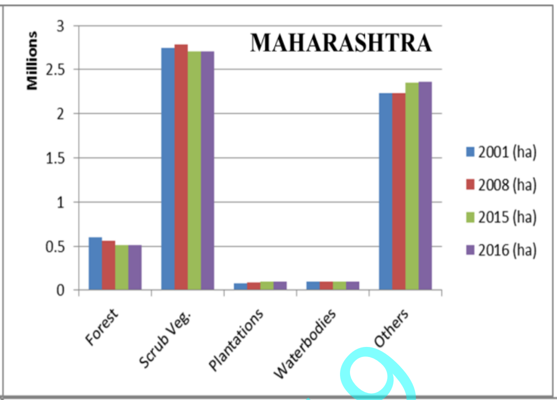
CLASSIFIED IMAGE	2016	REFERENCE IMAGE						
	Kerala Hills 2	Forest	Scrub Veg.	Plantation	Water bodies	Others	Total	Producer's Accuracy
	Forest	24	1	3	0	0	28	0.85
	Scrub Veg.	0	9	1	0	0	10	0.9
	Plantation	2	2	7	0	0	11	0.63
	Waterbodies	0	0	0	9	1	10	0.9
	Others	0	2	0	0	8	10	0.8
	Total	26	14	11	9	9	69	0
	Producer's Accuracy	0.92	0.64	0.63	1	0.88	0	0.82
	Kappa							0.77

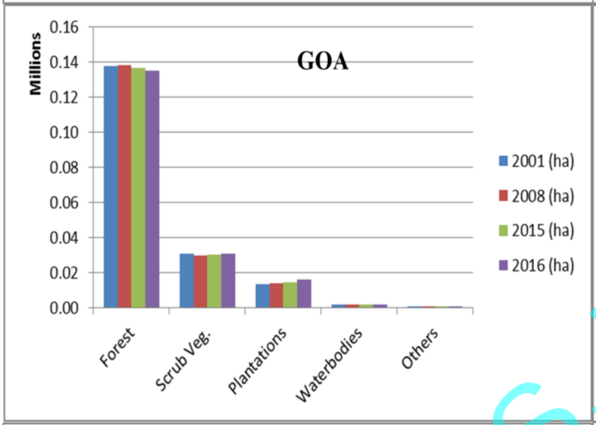
A1: Error Matrix

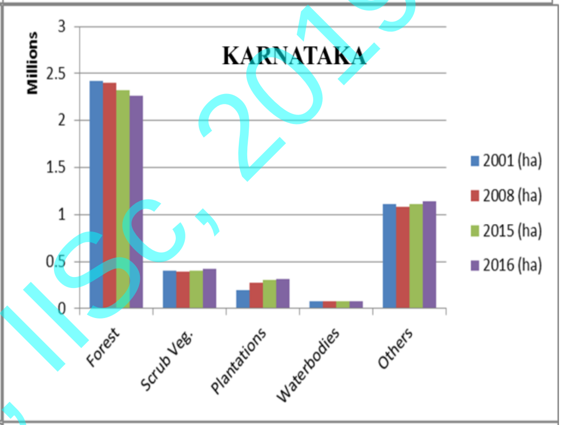
(b) Area under different LU class:

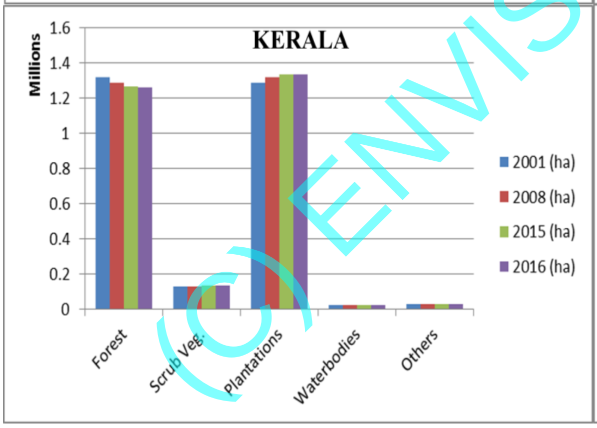
The area under different land use class and the change in different periods of study is depicted in Fig. A1

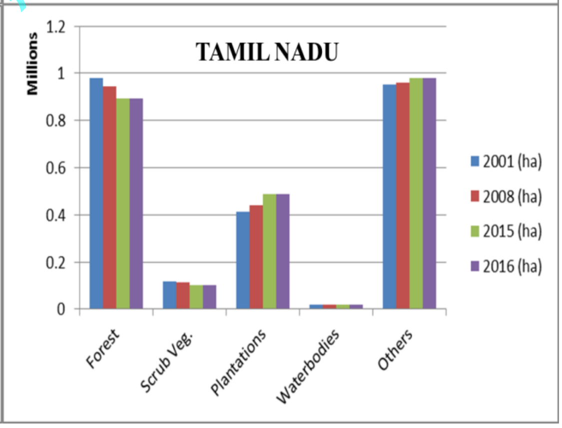


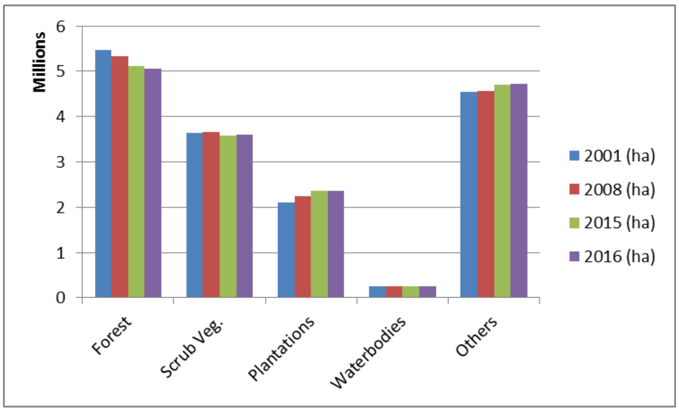












A1: Area under different LU class

REFERENCES:

1. Ado, H.Y., 1992. Numerical study of the daytime urban effect and its interaction with the sea breeze. *Journal of Applied Meteorology*, *31*(10), pp.1146-1164
2. Alder, D. and Synnott, T.J., 1992. *Permanent sample plot techniques for mixed tropical forest*. Oxford Forestry Institute, University of Oxford.
3. Botkin, D.B., Estes, J.E., MacDonald, R.M. and Wilson, M.V., 1984. Studying the earth's vegetation from space. BioScience, pp.508-514.
4. Bonan, G.B., 2008. Forests and climate change: forcings, feedbacks, and the climate benefits of forests. *science*, *320*(5882), pp.1444-1449.
5. Bwangoy, J.R.B., Hansen, M.C., Roy, D.P., De Grandi, G. and Justice, C.O., 2010. Wetland mapping in the Congo Basin using optical and radar remotely sensed data and derived topographical indices. *Remote Sensing of Environment*, *114*(1), pp.73-86.
6. Campbell, J.B. and Wynne, R.H., 2011. *Introduction to remote sensing*. Guilford Press.
7. Cameron, 2009. EXCEL: Multiple Regression (January 2009). Available at: http://cameron.econ.ucdavis.edu/excel/ex61multipleregression.html (Accessed on June 25, 2017)
8. Chandran, M.S., 1997. On the ecological history of the Western Ghats. *Current Science*, pp.146-155.
9. Chen, J., Chen, J., Liao, A., Cao, X., Chen, L., Chen, X., He, C., Han, G., Peng, S., Lu, M. and Zhang, W., 2015. Global land cover mapping at 30m resolution: A POK-based operational approach. *ISPRS Journal of Photogrammetry and Remote Sensing*, *103*, pp.7-27.
10. Cran, D.G., McKelvey, W.A.C., King, M.E., Dolman, D.F., McEvoy, T.G., Broadbent, P.J. and Robinson, J.J., 1997. Production of lambs by low dose intrauterine insemination with flow cytometrically sorted and unsorted semen. *Theriogenology*, *1*(47), p.267.
11. Colombi, A., De Michele, C., Pepe, M., Rampini, A. and Michele, C.D., 2007. Estimation of daily mean air temperature from MODIS LST in Alpine areas. *EARSeL eProceedings*, *6*(1), pp.38-46.
12. Crippen, R.E., 1990. Calculating the vegetation index faster. Remote Sensing of Environment, 34(1), pp.71-73.
13. Friedl, M.A., McIver, D.K., Hodges, J.C., Zhang, X.Y., Muchoney, D., Strahler, A.H., Woodcock, C.E., Gopal, S., Schneider, A., Cooper, A. and Baccini, A., 2002. Global land cover mapping from MODIS: algorithms and early results. Remote Sensing of Environment, 83(1), pp.287-302.
14. Friedl, M.A., McIver, D.K., Hodges, J.C., Zhang, X.Y., Muchoney, D., Strahler, A.H., Woodcock, C.E., Gopal, S., Schneider, A., Cooper, A. and Baccini, A., 2002. Global land cover mapping from MODIS: algorithms and early results. *Remote Sensing of Environment*, *83*(1), pp.287-302.

15. Fu, B., Chen, L., Ma, K., Zhou, H. and Wang, J., 2000. The relationships between land use and soil conditions in the hilly area of the loess plateau in northern Shaanxi, China. *Catena*, *39*(1), pp.69-78.
16. Gadgil, M., 2014. Western Ghats Ecology Expert Panel. Economic & Political Weekly, 49(18), p.39.
17. Ganasri, B.P. and Dwarakish, G.S., 2015. Study of land use/land cover dynamics through classification algorithms for Harangi catchment area, Karnataka State, India. *Aquatic Procedia*, *4*, pp.1413-1420.
18. Giuliano, G. and Small, K.A., 1991. Subcenters in the Los Angeles region. *Regional science and urban economics*, *21*(2), pp.163-182.
19. Gonzalez, R.C., Fry, D.N. and Kryter, R.C., 1974. Results in the application of pattern recognition methods to nuclear reactor core component surveillance. *IEEE Transactions on Nuclear Science*, *21*(1), pp.750-756.
20. Hansen, A.J. and DeFries, R., 2007. Ecological mechanisms linking protected areas to surrounding lands. *Ecological Applications*, *17*(4), pp.974-988.
21. Hansen, M.C., Potapov, P.V., Moore, R., Hancher, M., Turubanova, S.A., Tyukavina, A., Thau, D., Stehman, S.V., Goetz, S.J., Loveland, T.R. and Kommareddy, A., 2013. High-resolution global maps of 21st-century forest cover change. science, 342(6160), pp.850-853
22. Hansen, Jim., World of change (May, 2017). Available at : https://earthobservatory.nasa.gov/Features/WorldOfChange/decadaltemp.php. (Accessed on 15 May, 2017)
23. Helmer, E.H., 2000. The landscape ecology of tropical secondary forest in montane Costa Rica. *Ecosystems*, *3*(1), pp.98-114.
24. Huete, A., Justice, C. and Van Leeuwen, W., 1999. MODIS vegetation index (MOD13). *Algorithm theoretical basis document*, *3*, p.213.
25. Jain, S.K. and Chaudhary, A. , 2010. Forest Cover Assessment of Uttranchal State (December 13, 2010). Available at: https://www.geospatialworld.net/article/forest-cover-assessment-of-uttranchal-state/ (Accessed on: April 20, 2017)
26. Jennings, S.B., Brown, N.D. and Sheil, D., 1999. Assessing forest canopies and understorey illumination: canopy closure, canopy cover and other measures. *Forestry*, *72*(1), pp.59-74.
27. Jha, C.S., Dutt, C.B.S. and Bawa, K.S., 2000. Deforestation and land use changes in Western Ghats, India. *Current Science*, pp.231-238.
28. Kasturirangan, K., 1985. The evolution of satellite-based remote-sensing capabilities in India. *International Journal of Remote Sensing*, *6*(3-4), pp.387-400.
29. Klein Goldewijk, C.G.M. and Battjes, J.J., 1997. A hundred year (1890–1990) database for integrated environmental assessments (HYDE, version 1.1). National institute of public health and the environment (RIVM), Bilthoven, the Netherlands.
30. Kriegler, F.J., Malila, W.A., Nalepka, R.F. and Richardson, W., 1969. Preprocessing transformations and their effects on multispectral recognition. In Remote Sensing of Environment, VI (p. 97).

31. Kusangaya, S., Warburton, M.L., Van Garderen, E.A. and Jewitt, G.P., 2014. Impacts of climate change on water resources in southern Africa: A review. *Physics and Chemistry of the Earth, Parts A/B/C*, *67*, pp.47-54.
32. Lambin, E.F., Turner, B.L., Geist, H.J., Agbola, S.B., Angelsen, A., Bruce, J.W., Coomes, O.T., Dirzo, R., Fischer, G., Folke, C. and George, P., 2001. The causes of land-use and land-cover change: moving beyond the myths. Global environmental change, 11(4), pp.261-269.
33. Lambin, E.F., 1997. Modelling and monitoring land-cover change processes in tropical regions. *Progress in physical geography*, *21*(3), pp.375-393.
34. Lambin, E.F., Geist, H. and Rindfuss, R.R., 2006. Introduction: local processes with global impacts. In *Land-use and land-cover change* (pp. 1-8). Springer Berlin Heidelberg.
35. Lepers, E., Lambin, E.F., Janetos, A.C., DeFries, R., Achard, F., Ramankutty, N. and Scholes, R.J., 2005. A synthesis of information on rapid land-cover change for the period 1981–2000. *AIBS Bulletin*, *55*(2), pp.115-124.
36. Lillesand, T., Kiefer, R.W. and Chipman, J., 2014. *Remote sensing and image interpretation*. John Wiley & Sons.
37. Lindquist, E.J., Hansen, M.C., Roy, D.P. and Justice, C.O., 2008. The suitability of decadal image data sets for mapping tropical forest cover change in the Democratic Republic of Congo: implications for the global land survey. *International Journal of Remote Sensing*, *29*(24), pp.7269-7275.
38. Mohan., 2008. Geopolitical Profile – Girdling Six States (July 30, 2008). Available at: http://westernghats-paimohan.blogspot.in/2008/07/geopolitical-profile.html/ (Accessed on April 20, 2017)
39. MoEF., 2015. State of Forest – Report (2015). Available at: http://fsi.nic.in/details.php?pgID=sb_62 (Accessed on May 10, 2017)
40. Mountford, E.P. and Peterken, G.F., 2003. Long-term change and implications for the management of wood-pastures: experience over 40 years from Denny Wood, New Forest. *Forestry*, *76*(1), pp.19-43.
41. Patra, P., 2010. Remote Sensing and Geographical Information System (GIS). *The Association for Geographical studies*.
42. Pelleg, D. and Moore, A.W., 2000, June. X-means: Extending K-means with Efficient Estimation of the Number of Clusters. In *ICML* (Vol. 1, pp. 727-734).
43. Peterken, G.F., 1974. A method for assessing woodland flora for conservation using indicator species. *Biological Conservation*, *6*(4), pp.239-245.
44. Sánchez-Cuervo, A.M., Aide, T.M., Clark, M.L. and Etter, A., 2012. Land cover change in Colombia: surprising forest recovery trends between 2001 and 2010. *PLoS One*, *7*(8), p.e43943
45. Schielzeth, H., 2010. Simple means to improve the interpretability of regression coefficients. *Methods in Ecology and Evolution*, *1*(2), pp.103-113.
46. Sathe, P.V. and Chauhan, O.S., 2003. The saga of Sahyadri: societal environmental issues of Konkan and Goa. *Recent Advances in Environmental Science*, pp.26-35.

47. Setiawan, Y. and Yoshino, K., 2012. Change detection inland-use and land-cover dynamics at a regional scale from modis time-series imagery. *ISPRS Annals of the Photogrammetry, Remote Sensing and Spatial Information Sciences*, *7*.
48. Setiawan, Y., Yoshino, K. and Prasetyo, L.B., 2014. Characterizing the dynamics change of vegetation cover on tropical forestlands using 250m multi-temporal MODIS EVI. *International Journal of Applied Earth Observation and Geoinformation*, *26*, pp.132-144.
49. Setturu, B. and Ramachandra, T.V., 2012. Landscape dynamics of Uttara Kannada district. In *National Conference on Conservation and Management of Wetland Ecosystems*.
50. Wan, Z., 2007. Collection-5 MODIS land surface temperature products users' guide. *ICESS, University of California, Santa Barbara*.
51. Whitman, 2016. The Ecosystem and how it relates to Sustainability (October 24, 2016). Available at: https://globalchange.umich.edu/globalchange1/current/lectures/kling/eco-system/ecosystem.html/ (Accessed on April 30, 2017).