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Remote Sensing and GIS for Monitoring and Assessing Forest Susceptibility to Climate Change: A Spatio-Temporal Study on Protected Area of Western Ghats, India

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Abstract:- Mapping and monitoring land use/ land cover (LULC) and assessing land surface temperature (LST), are essential for understanding the effect of climate change for formulation of long-term conservation plan. In this study, remote sensing and geographic information system (GIS) were used to assess LULC and LST variation in the Chinnar Wildlife Sanctuary from 2008 to 2021 and 2001 to 2021 respectively. Landsat-8, Landsat-5 images and ArcGIS 10.3.1, were employed in the analysis. The LULC maps for the research areas were generated by supervised classification with the method called maximum likelihood classification (MLC).The findings of the study revealed that dry deciduous forest type is the most prevalent vegetation type in the study area followed by scrub jungle. According to the change detection matrix, dry deciduous forest and scrub jungledecreased by 546.8 hectares (13%) and 128.43 hectares (3%), respectively. However, open areas of the sanctuary have increased by 39% over 13 years of interval. The LST of the sanctuary also shows an increasing trend between 2001 and 2021. The reduction in vegetation might be the reason for the increase in the LST of the study area.

Index Terms:Land use / Land cover, Land Surface Temperature, Remote sensing, Geographic Information System, Western Ghats

I. Introduction

The climate change that we are witnessing in this century is affecting the health and function of the biosphere. Forest ecosystems play an important role in the environment. Forests help in maintaining the biogeochemical cycle, carbon sequestration, and the decomposition of dead organic matter, along with numerous social and cultural benefits. Forests are made up of various ecosystems that are related to varying edaphic and microclimate conditions (Thompson *et al.*, 2009). Out of a total rural population of 3.4 billion, 1.3 billion live in or around the world's remaining forests (Chao, 2012). However, human influences have resulted in the loss of 40% of forests worldwide (WWF, 2020).Recent studies have shown that the composition, structure, and function of forest ecosystems are rapidly changing in response to climate change and other anthropogenic activities (Yu *et al.*, 2021).

The Western Ghats (WG)- a UNESCO World Heritage Site, spanning across the western coast of peninsular India is a biodiversity hotspot (Myers *et al.*, 2000). It is home to many threatened and endemic species (Daniels, 2003). The forests of the WG are home to some of the world's best examples of non-equatorial tropical evergreen forests, heavy seasonal rainfall and various soil types such as red soils, laterite soils, black soils, and humid soils support wide variety of flora and fauna. (Subramanyam and Nayar, 1974). According to UNESCO (2012) report, there are 325 globally threatened species that inhabit the WG. Out of 325 species, 129 species belong to vulnerable category, 145 and 51 belongs toendangered and critically endangered category, respectively.

Studies conducted across three states (Karnataka, Kerala, and Tamil Nadu) from 1973 to 1995 have revealed a loss of 25.6 percent forest cover in the WG (Jha, *et al.*, 2000). According to reports, there was a steady but considerable loss of forest cover in numerous WG regions (Reddy *et al.*, 2016). For example, in the Karnataka district of Uttara Kannada Forest cover dropped by half (Gadgil, 1996), while the evergreen forest in Kerala is on the verge of extinction (Ramesh *et al.*, 1997). The significant drivers of vegetation loss in the WG are deforestation, land-use changes livestock grazing, invasive species and the direct and indirect impacts of climate change (Jha *et al.*, 2000, Chethana and Ganesh, 2013, Pramanik*et al.,* 2018). Identifying existing stress and monitoring vegetation response to climate change are essential for creating long -term mitigation and adaptation strategies.

Satellite sensors have become more critical in recent years for analysing plant dynamics and temperature changes at regional and global scales (Ssemmanda*et al.*, 2014, Cao 2018).For example, Aditya and Reghunath (2016) assessed LULC change in Shendurney Wildlife Sanctuary, Vijayasoorya and Reghunath (2016) in Neyyar Wildlife Sanctuary, Panaskar (2019) evaluated land cover change by comparing NDVI (Normalized Difference Vegetation Index) and NDWI (Normalized Difference Water Index) in WG. Studies by Ramachandran *et al.,* (2017) showed that there were unusual changes in LULC and the increase in LST reduced the species regeneration pattern.

Chinnar Wildlife Sanctuary is an ecologically important area located in the rain shadow region of the WG. The region is home to several endangered and threatened species. Human access to the forest altered the vegetation of the sanctuary, resulting in loss of canopy continuity and diversity (Jayson and Ramachandran, 1996).

In the present study,remote sensing and GIS were employed to assess LULC classes and change in vegetation pattern of Chinnar Wildlife Sanctuary from 2008 to 2021. The LST patterns were assessed from 2001 to 2021. The study of LULC dynamics and LST changes will aid in the development of sustainable land management strategies.

II. Materials and Methods

A. *Description of the Study Area; -*

Chinnar Wildlife Sanctuary was a protected area of WG located in the Eastern section of Southern WG (Figure 1). Chinnar is situated in DevikulamTaluk of the Idukki district, Kerala, India. The temperature sanctuary lies between 10° 15’ to 10° 21’ N latitude 77° 05’ to 77° 16’ E longitude. The total area of 90.44 km².The temperature in this area ranges from 12˚C to 38˚C, and the yearly average rainfall is barely 500 mm (Ajin, et al., 2016).The areas altitude ranges from 440 m to 2372 m (Jayson and Ramachandran, 1996).

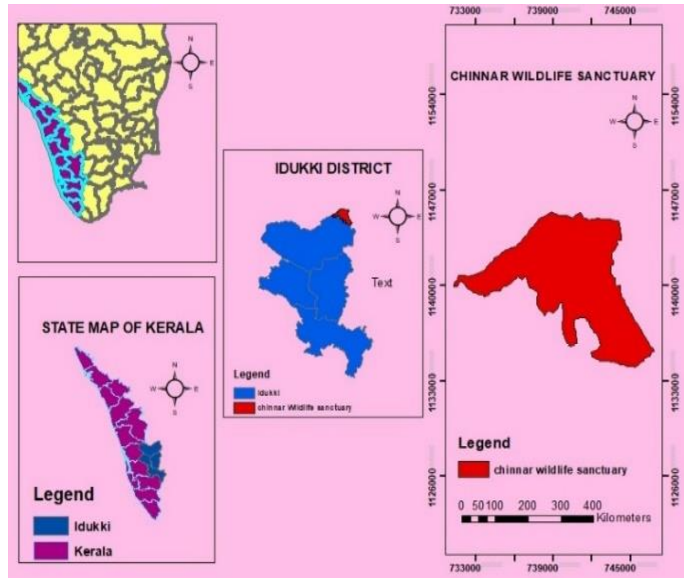


Fig.1 Study area map of Chinnar Wildlife Sanctuary

According to Champion and Seth (1999),the predominant vegetation types of the sanctuary are scrub jungle, dry deciduous forest, moist deciduous forest and riparian forest. The grizzled squirrel and Indian star tortoise are endemic to the sanctuary. It is also home to *Albizialathamii*a critically endangered plant endemic toreserve(Sajeev and Sasidharan, 1998). The wide variety of flora and fauna with many endemic species makes the sanctuary suitable for the current study.

B. *Data Collection*

The satellite images of Landsat 8 (OLITIRS) and Landsat 5 (TM,MSS) for the study area was downloaded from the USGS Earth explorer in .tiff format. The datafile consist of seven bands (Table 1) having resolution of 30m (Table 2). To minimize the effect of atmospheric noise on image classification, cloud cover was limited to less than 10%. The collected GeoTIFF format images were projected to the World geographic coordinate system 1984. ArcGIS 10.3.1 was used to retrieve LULC and LST results.

Landsat 5 was developed by NASA and launched by Vandenberg air force base in California on March 1, 1984. It had a maximum transmission bandwidth of 85 Mbit/s and was deployed at an altitude of 705.3 km. Landsat 5 carries two sensors such as thematic mapper (TM) and multi-spectral scanner (MSS). One of the important features of Landsat 5 is it carriedinformation for nearly 29 years. It was officially decommissioned on June 5, 2013. Landsat 8 was launched on an Atlas-V rocket from Vandenberg Air Force Base, California on February 11, 2013 (Zakerinejad et al., 2022). The satellite carries the Operational Land Imager (OLI) and the Thermal Infrared Sensor (TIRS) instruments(USGS 2022).

Landsat 5 is high resolution satellite images help to get more accurate results in regional scale particularly in tropical areas. It is commonly used satellite for monitoring land use land cover change and provides good accuracy results over a long year period. Landsat 5 is not recommended for wide area applications. The strong correlation between the spectral signals of visible bands is another drawback of Landsat 5 data.

Table 1 and 2 contains the information about the satellite data used for LULC and LST analysis, respectively. Bands relevant to vegetation and temperature were chosen for LULC and LST analysis.

Table 1., Band composition for Landsat 8 and Landsat 5

RGB Composite	Landsat 8-Bands	Landsat 5-Bands
Natural Color	4 3 2	3 2 1
False Color (urban)	7 6 4	7 5 3
Color Infrared (vegetation)	5 4 3	4 3 2
Agriculture	6 5 2	5 4 1
Atmospheric Penetration	7 6 5	7 5 4
Healthy Vegetation	5 6 2	4 5 1
Land/Water	5 6 4	4 5 3
Natural With Atmospheric Removal	7 5 3	7 4 2
Shortwave Infrared	7 5 4	7 4 3
Vegetation Analysis	6 5 4	5 4 3

Table 2., Description of the satellite data used in this study

Date of images	Satellite Sensor	Resolution	Band Used
2/03/2021	Landsat 8 (LULC)	30 m	1,2,3,4,5,6,7
27/03/2008	Landsat 5 (LULC)	30 m	1,2,3,4,5,6,7
15/03/2021	Landsat 8 (LST)	30 m	10,11
10/03/2001	Landsat 5 (LST)	30 m	6

C. *Estimation of Land surface temperature*

LST measures theradiativephysical temperature of the earth's surface, where incoming solar energy interacts and warms the Earth(Hulley*et al.*, 2019). In forest, LST is the temperature of the canopy. The calculation of LST involves different steps. They are:

1) *Conversion to TOA (Top of Atmospheric) Radiance*

The Top-of-Atmosphere (TOA) is a critical feature of the climate system. TOA describes the amount of solar energy that the earth absorbs and the amount of terrestrial thermal infrared radiation it emits(Leob*et al.*, 2018). It is calculated by Eq(1)

$$L_\lambda = M_L Q_{cal} + A_L \quad \text{(Eq.1)}$$

Where:

L_λ= spectral radiance of TOA (Watts/(m^2 * S $_{rad}$ * m)

M_L = Metadata band-specific multiplying real-world measurement by the scaling factor

A_L = Metadata band-specific adding real-world measurement by the scaling factor

Q_{cal}= Pixel is an element of an image. Each pixel corresponds to any one value. Qcal is the pixel values for quantized and calibrated standard products (DN)

2) *Conversion to Top of Atmosphere Brightness Temperature*

For calculating atmosphere brightness temperature,the DN values in the image are converted into at-sensor spectral radiance which is then translated into atmosphere sensor brightness temperature (K). The conversion formula is,

$$BT = (K_2 / (\ln (K_1 / L) + 1)) - 273.15 \quad \text{(Eq.2)}$$

Where:

L = TOA spectral radiance is measured in (Watts/ (m2 * S_{rad} * m)) by measuring the radiation in different wavelengths.

K_1&K_2 = Thermal conversion constant

3) *Assessment of Normalized Difference Vegetation Index*

In forests, the NDVI index evaluates the variation between red and near-infrared bands. The NDVI is used to assess the health of plant cover. The index value can vary between -1 and +1. The dense vegetation shows positive value, whereas water and built-up areas will be near-zero or negative (Viana *etal.*,2019).

$$NDVI = NIR\text{-}RED/\ NIR+RED \quad \text{(Eq.3)}$$

Where, NIR (Near Infra-Red) and RED (visible) are the spectral reflectance.

4) *Calculation of proportion of Vegetation P_v*

P_V is defined as the "ratio of the vertical projection area of vegetation (containing leaves, stalks, and branches) on the ground to the total vegetation area"(Deardorff, 1978).

$$P_v = \text{Square}(NIR\text{-}RED/NIR+RED)–(NIR\text{-}RED/NIR+RED_{min})/(NIR\text{-}RED/NIR+RED)_{max} –(NIR\text{-}RED/NIR+RED)_{min} \quad \text{(Eq.4)}$$

5) *Calculate Emissivity (ε)*

The emissivity is the degree of emission of an object. It indicates the amount of radiation an object emits compared to an ideal heat emitter (a black emitter). The default value for emissivity is 1 without any units.

$$\varepsilon = 0.004 * P_v + 0.986 \quad \text{(Eq.5)}$$

0.986 corresponds to the equation's correction value.

6) *Conversion from Satellite Temperature to Land Surface Temperature*

Satellite temperatures are used to calculate the temperature of the atmosphere at various altitudes, as well as the earth's skin temperature. It's calculated as follows:

$$LST = BT/ [1+ (\lambda *TB/C_2) * \ln (e)] \quad \text{(Eq.6)}$$

Where,

BT=Temperature at the Top of Atmospheric Brightness

λ = wavelength of radiation emitted

C_2 = h*c

λ=14388Umk

h = Planck's constant and the value is 6.625×10^{-34}

S = Boltzmann constant and the value is $1.38*10^{-23}$

c = Velocity of light and the value is $2.988*10^{8}$m/s

e = Emissivity

D. *Mapping and assessing Land use/ Land Cover*

The categorization or classification of human activities and natural elements on the landscape over time, using established scientific and statistical methods of analysis of appropriate source materials, is referred to as LULC.The entire study field was divided into six major classifications for generating LULC map. The classifications include dry deciduous forest, scrub jungles, shola forest, open areas, and water bodies. The detailed description of the LULC classes is shown in the Table 4.

Table 3. Description of Land covers classes

LULC Class	Colour	Description of classes
Dry Deciduous Forest	Green	This type of vegetation is dominated with hardwood trees. The canopy is open with poor undergrowth.
Open Areas	Brown	Areas devoid of vegetation, areas covered by settlements, hill tops, land with treecanopy density between 10 and 40%.
Scrub Jungle	Yellow	The open low forest is characterisedby xerophytic species with short bole and low branching. The canopy is wide open.The hard wood trees and climbers are characteristic feature.
Shola forest	Dark green	High altitude evergreen closed forest is characterised by short boled and branchy species.
Water Bodies	Blue	Areas with surface water (eg. River, Watersheds, streams etc.)

1) *Image processing and Change Detection*

The image processing was accomplished with the help of the ArcGIS 10.3.1 software. The software was programmed using bands 1 to 6 and RGB band composites were built with the data management tool. The research area boundary map was clipped andsupervised image classification approach was used to classify the features. In this type of classification user can choose sample pixels in a picture that represent specific classes. Field visits were conducted to several portions of the forest for ground truth verification.

2) *Algorithm used for supervised classification*

In the present study applied Maximum Likelihood Classifier (MLC) algorithm technique applied for LULC image classification.MLC is a supervised classification method which is working based on Bayesian theory (Norovsuren 2019). MLC is based on the probability that a pixel belongs to one of several classes. The two most important components of maximum likelihood classification that can be obtained from training data are the mean vector and covariance metrics(Alkaradaghi 2018).

III. Results and Discussion

A) *LULC of the study area*

Figures 2 and 3 shows thespatial representations of the land use and land cover categories at Chinnar Wildlife Sanctuary (LULC).

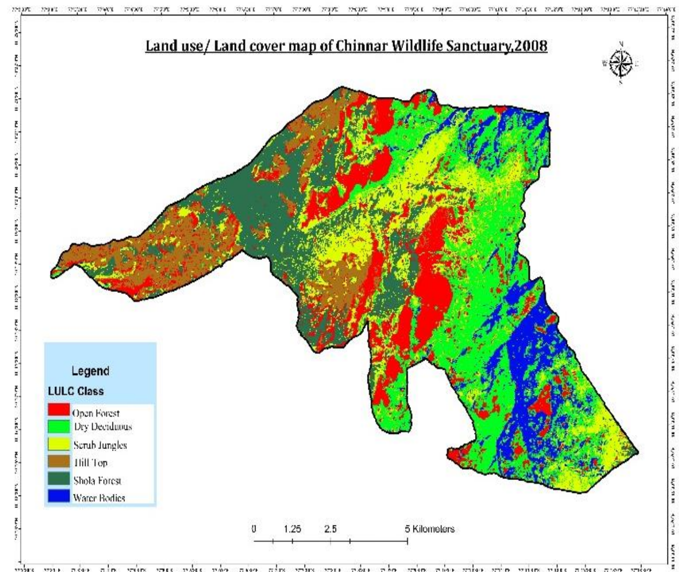
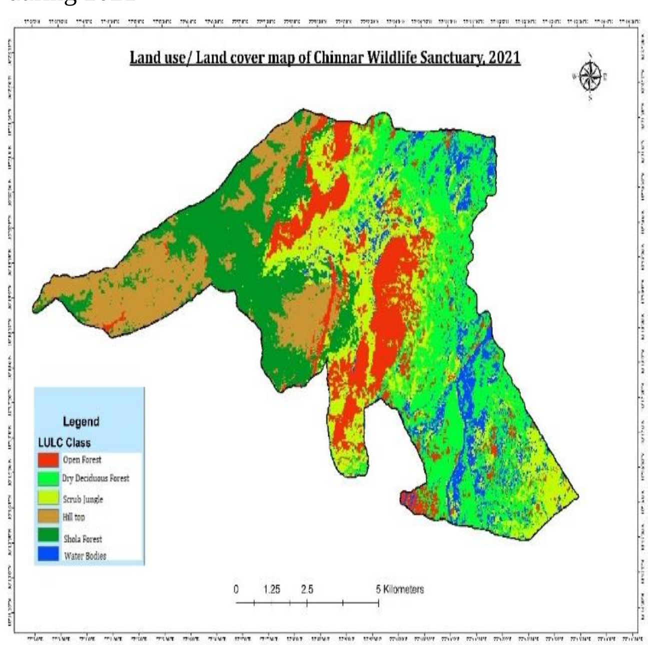


Fig.2 Landuse/ Landcover map of Chinnar Wildlife Sanctuary during 2008

Fig.3 Landuse/ Landcover map of Chinnar Wildlife Sanctuary during 2021



Using supervised classification, the entire protected area is classified into five major LULC types such as dry deciduous forest, scrub jungle, shola forest, open area, and water bodies. The image classification result found that the dry deciduous vegetation occupies the maximum area in the sanctuary, followed by the scrub jungle. The dry deciduous forest of the sanctuary is characterised by hardwood deciduous tree species with an open canopy and poor undergrowth. This type of vegetation is found at Palapetty, Alampetty, Ichampetty, Karimalai,Thayanankkudy and Puthukkudy regions of the sanctuary.

The most dominant species present in the forest type are *Anogeissuslatifolia, Chloroxylonswietenia, Hardwickiabinata, etc. (*Sasidharan 1999). Scrub jungle is the least common forest type in Kerala, yet it is the second most common forest type in Chinnar Wildlife Sanctuary in terms of area. The vegetation is characterised by xerophytic species such as Acacia spp., Euphorbia spp., Capparis spp., Opuntia spp., Ziziphus spp., Grewia spp., Cordiu spp., Caralluma spp., Helixanthera spp. etc.This forest type can be found in Chinnar, Champakkad, Chunkam, Nellimedu, and the slopes of Alampetty, Ichampetty, and Palapetty, among other places. The shola vegetation of the Chinnaris characterised by branchy species found in two locations: Olikkudy shola and Kariveppin shola, at elevations above 1300m msl.The shola vegetation is the only undisturbed forest type of the sanctuary that is dominated by Syzygium spp.,Pittosporum spp., *Elaeocarpusrecurvatus, Actinodaphnemalabarica, Agrostistachysindica, Fagraeaceylanica, Cryptocaryaanamallayana, Calamusgamblei, Gordoniaobtusa, Mallotustetracoccus, Aglaiaelaeagnoidea, Gomphandracoriacea.*

Table 4LULC changes between 2008 and 2021

LULC Class	Area 2008 (ha)	%	Area 2021 (ha)	%
Dry Deciduous Forest	4048.1	42%	3501.3	36%
Open Areas	420.94	4%	704.5	7%
Scrub Jungle	3346.5	35%	3218.07	33%
Shola forest	1299.5	13%	1690.5	18%
Water Bodies	537.5	6%	538.43	6%
Total	9652.54	100%	9652.8	100%

Champion and Seth classification shows that Chinnar is dominated with dry deciduous forest type. Present study found that much of the dry deciduous vegetation type declined in the last thirteen years, followed by scrub jungle. The dry deciduous forest of the sanctuary shrank from 4048.1hectares to 3501.3hectares between 2008 and 2021 which is a loss of 546.8 hectares (13%). Scrub jungle, on the other hand, has declined from 3346.5 hectares in 2008 to 3218.07 hectares in 2021, representing a loss of 128.43 hectares (3%). The decrease in these vegetation types could be attributed to the increase in the frequency of forest fires within the protected area (Ajin*et al.*, 2016).

The shola forest, on the other hand, expanded from 1299.5 hectares in 2008 to 1690.5 hectares in 2021, a gain of 391 (23%) hectares over the two time periods. Jayson and Ramachandran (1996) reported that vegetation growth of the Chinnar Wildlife Sanctuary has increased as a result of the intensive fire protection activities. It is also reported that with the exception of Idukki, where the sanctuary is located, many dense forests in the WG are being degraded as a result of habitat fragmentation. A significant increase in open areas (about 39%) was also detected. The increase in open areas is attributed to the high level of human interference within the protected area. For example, the riverine vegetation from the Chinnar checkpoint to Kootar on the Kerala side underwent severe deterioration. This stretch has several vulnerable areas due to the narrow width of the riverine vegetation. If adequate protection is not provided, the canopy's continuity may be disrupted affecting the survival of many species. The interaction of humans, particularly tribes, with the forest for fuel wood and lemon oil extraction is cited as a reason for expanding open areas of the protected areas (Sasidharan, 1999).There isn't much difference in the water bodies.

B) LST of the study area

Figures 4 and 5 depict the variance in LST in the Chinnar Wildlife Sanctuary. The study observed maximum LST in the study area in 2001 was 33.26℃, and it increased by 35.06℃ in 2020.

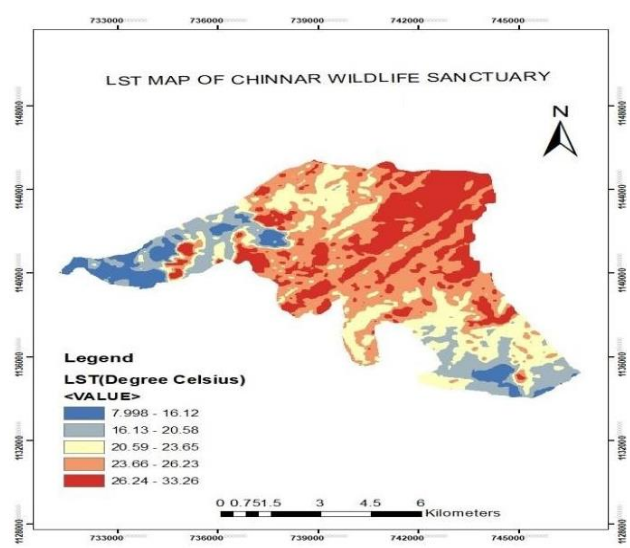


Fig.4 Land Surface Temperature map of Chinnar Wildlife Sanctuary during 2001

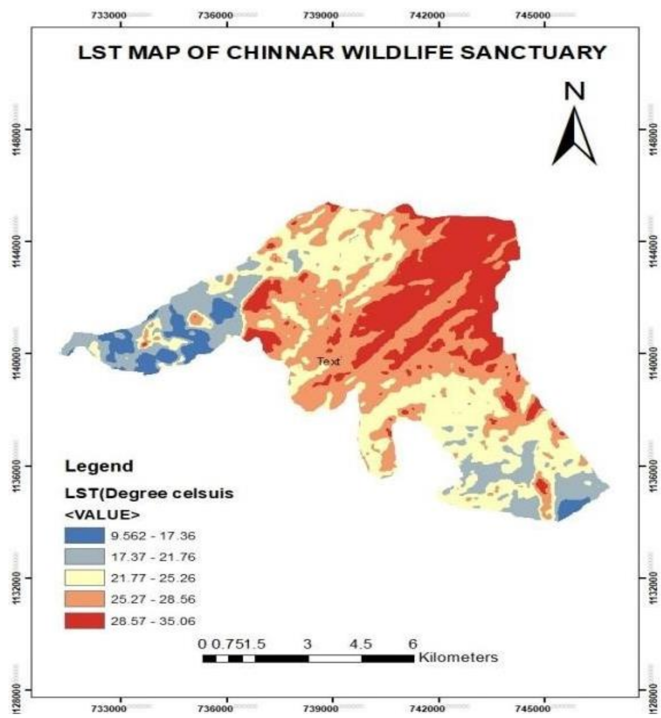


Fig.5 Land Surface Temperature map of Chinnar Wildlife Sanctuary during 2021

Forest cover loss could be an important factor responsible for the increase in LST. The loss of forest cover may be a significant contributor to the rise in LST.

CONCLUSION

Using remote sensing and GIS, the present study assessed and monitored temporal changes in the LULC and LST patterns in Chinnar Wildlife Sanctuary. The result shows adecrease in the amount of dry deciduous forests, scrub jungle (Southern tropical thorn forest), and a minor increase found shola forests. The study also found that open areas have been expanded significantly over a 13-year interval.These changes can be attributed to either direct or indirect human intervention inside the Wildlife Sanctuary. The LST analysis results from the entire study area show an increasing trend between 2001 and 2021.Land surface temperature typically decreases as forest cover increases. The present study found that the wildlife sanctuary is dominated by dry deciduous vegetation, which has declined over time. Declining primary vegetation of the sanctuary could be an attribute for increasing land surface temperature. The analysis and findings of the study have important policy implications for the sustainable land-use/cover practices in the sanctuary.

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