

ESTIMATION OF LAND SURFACE TEMPERATURE OF HIGH RANGE MOUNTAIN LANDSCAPE OF DEVIKULAM TALUK USING LANDSAT 8 DATA

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Abstract

Land Surface Temperature (LST) can be calculated through a thermal infrared remote sensing data. It can record the apparent temperature of the Earth's surface by measuring the radiant energy exiting its surface. With the advent of satellite images and digital image processing software, now it is possible to calculate LST. In this study, LST for Devikulam taluk was derived using Single Window algorithm (SW) with the use of Landsat-8 (Path-144 and Row-53) Thermal Infrared Sensor (TIRS) data of 100m resolution. Emissivity was derived with the help of NDVI proportion of vegetation technique for which Operational Land Imager (OLI) bands 4 and 5 (30 m resolution) were used. The results showed that surface temperature was high in the barren regions whereas it was low in the thick vegetation cover regions. As the SW algorithm uses both OLI and TIRS bands, the LST derived using them were more reliable and accurate.

Keywords: Land Surface Temperature, Single Window Algorithm, NDVI, OLI, TIRS

1. INTRODUCTION

Remote Sensing is the noncontact recording of information from the ultraviolet, visible, infrared and microwave regions of the electromagnetic spectrum by means of instruments such as cameras, scanners, lasers, linear arrays, and/or area arrays located on platforms such as aircraft or space craft and the analysis of acquired information by means of visual and digital image processing (John R. Jensen, 2009). In the present day, advancement of Satellite data has widely used in environmental related studies and climate change. Thermal bands of Landsat 8 is a significant one in Land Surface Temperature (LST) calculation. LST, the skin temperature of the ground, is identified as a significant variable of micro climate and radiation transfer within the atmosphere (Prasad Rajendran et.al, 2015). Land Use/Land Cover of an area is an important one in the estimation of LST amount. The natural and anthropogenic activities change the physical and biological condition of a region. This also influences LST of that area. As its value changes the local climate of the area also changes (Rajeshwari et.al, 2011). A traditional way of surface temperature estimation such as meteorological department weather station and other public and private sector observation is not feasible for all types of terrain condition and also it is a time consuming one. But remote sensing satellites provide data for any topographic and climatic condition of the region especially distinctive local climates (micro climates) produced by different land surfaces. NASA Landsat program provide different resolution satellite imagery for various periods at free of cost. Landsat 8 comes with two different sets of images from Operation Land Imager (OLI) with nine bands (30 m resolution) and Thermal Infrared

Sensor (TIRS) with two bands (band 10 and band 11 with 100 m resolution) which is useful in providing more accurate surface temperatures. TIRS uses Quantum Well Infrared Photo detectors (QWIPs) to detect long wavelengths of light emitted by the Earth whose intensity depends on surface temperature. (<http://landsat.gsfc.nasa.gov/?p=1940>). Since surface temperatures directly related with surface physical properties, Normalized Difference Vegetation Index (NDVI) is ideal for estimating LST in the high range mountain landscape.

1.1 Review of Literature

Land Surface integrated with Temperature (LST), the skin temperature of the ground, is identified as a significant variable of microclimate and radiation transfer within the atmosphere. In this study, author used Landsat TIRS and OLI data to estimate Land Surface Temperature Variation over Thiruvananthapuram, Capital city of the state of Kerala. In this study, potentials of semi-Automatic classification plug in integrated with open source GIS package Quantum GIS have been utilized for image acquisition, pre-processing, land cover classification and derivation of LST from land surface. Land surface temperature is the skin temperature of surface soil-water content and vegetation cover (Prasad Rajendran et. al, 2015). LST of the urban Erzurum was estimated using Landsat 8 OLI and TIRS having 12 bit radiometric resolution. LST was evaluated on the basis of surface emissivity and brightness values. In order to validate the LST derived from Landsat 8 bands, kinetic surface temperature measurements acquired from General

Directorate of State Meteorological Service in and around of the study area were incorporated. The result shows that maximum temperature difference was 6.45°C and minimum difference was 1.86°C . In addition to that land use / land cover and LST derived from Landsat 8 were compared and the temperature difference were reckoned (Ayse Dagliyar et.al, 2015). Landsat Thematic Mapper (TM) imagery from 1994, 2000 and 2009 were used to identify rapidly urbanized area of the Bangkok metropolitan area thermal characteristics by investigating the correlation between the land surface temperature (LST) and Normalized Difference Vegetation Index (NDVI). In this study, NDVI and LST were found to be closely correlated in several land use and land cover categories, especially in vegetated areas. Decrease of biomass primarily triggered the impacts of urban expansion on LST (Manat SRIVANIT et al, 2012). High resolution sequence satellite data have used to analyse LST over a watershed area in Iowa were analysed. LST images extracted from Landsat 5 Thematic Mapper (TM) and Landsat 7 Enhanced Thematic Mapper (ETM) thermal bands. NDVI derived from Landsat visible (band 4) and near-infrared bands (band 5) were used to estimate emissivity for landsat thermal bands. The estimated LST value was compared with ground truth measurements. The actual differences between the LST estimated from Landsat 5 and 7 and the ground truth actual measurements was 0.980c and 1.470c respectively. Thus the spatial differences of LST have identified using these satellite images (Fuquin

Li et.al, 2004). The relationship between land use / land cover change and the LST were assessed using Landsat 5 TM and ETM images. In order to derive land use classification object – based method was involved. On the other hand retrieval of LST was followed the mono-window algorithm. The deriving results indicated that LST was highly influenced by the land use land cover. LST was found to be positively correlated with impervious surface and vice versa. This study strongly recommended that such a study should be possible to apply where regions that are undergoing a rapid urbanisation (Zhi-qiang LV et. Al, 2011). Landsat 5 TM, Landsat 7 ETM for the year 1990, 2001 and 2010 had been used to estimate LST through the Landsat 7 user hand book method in Devikulam taluk. The results shows the mean temperature is increasing steadily (Suresh et.al, 2015).

1.2 Study Area

The area selected for the present study is high range mountain landscape of Devikulam Taluk located on the eastern slopes of Western Ghats (Map.1). The study area stretches between the latitudes of $9^{\circ}56'56''\text{N}$ to $10^{\circ}21'29''\text{N}$ and longitudes of $77^{\circ}48'31''\text{E}$ to $77^{\circ}16'14''\text{E}$ covers an area of 1140 Km^2 and is inhabited by 1,75,000 persons (Census 2011).

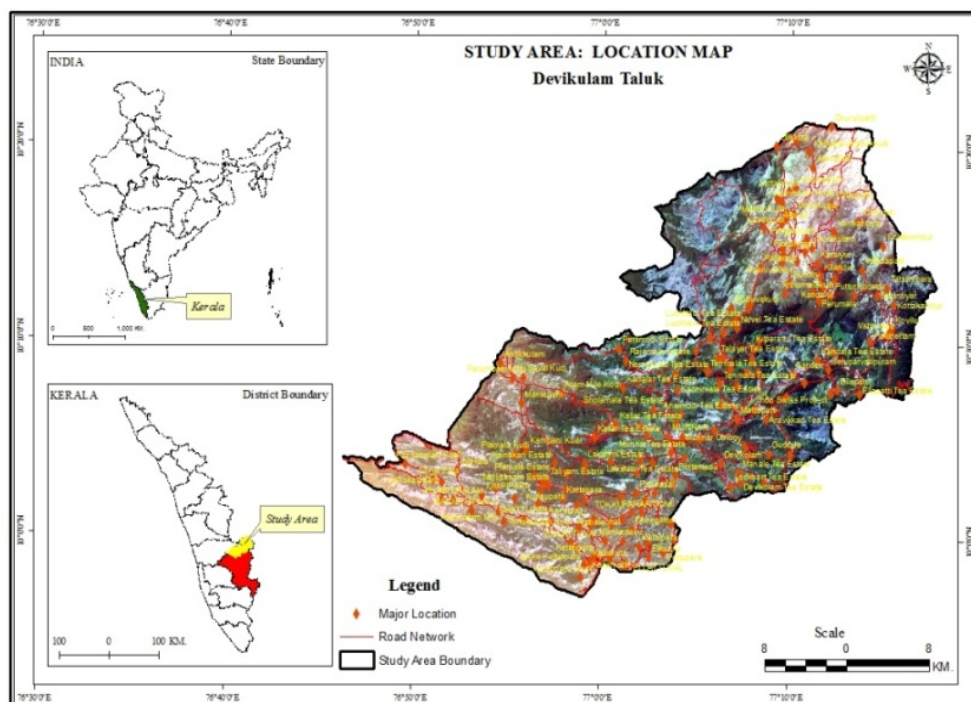


Fig-1: Study Area Map

Until the beginning of the latter half of the 19th century, the study area was under thick, virgin and impenetrable forest cover. However, the region has been cleared and converted to plantations with the advent of British rule in the country. The rapid extension of plantations in the taluk gradually transformed the economic as well as the demographic

structure which existed in the area. Now it is considered as one of the sixteen threatened ecological locations in the world. The annual mean temperature is also gradually increasing due to some climatic phenomena but it is mainly because of land cover changes.

2. MATERIALS AND METHODS

Landsat 8 is the latest among the Landsat series of NRSA. The data of Landsat 8 is available in Earth Explorer website at free of cost. In this study, Landsat 8 OLI and TIRS images of April 2014 (Path/Row - 144/053) pertaining to the study area was used to calculate NDVI and the estimation of LST. Mono – window algorithm method has employed to find out LST in the study area. Survey of India (SOI) toposheets with 1:50,000 scale have used as the base for the present study. Vegetation proportion calculation, emissivity calculation, LST calculation etc were executed in ArcGIS 9.3 software platform. Detailed description of the methodology is outlined here.

2.1 Image Acquisition and Pre-processing

Landsat 8 TIRS and OLI images with meta data (MTL) file for the study area (Path/Row – 144 / 053) downloaded from Earth Explorer website. The images were already rectified to WGS-1984-UTM-Zone_43N. The next step involved is the conversion of DN (Digital Number) to the physical measure of Top of Atmospheric Reflectance (TOA) given in the metadata file and the Thermal band to At-Satellite Brightness Temperature. The file with extension .MTL provided in the Landsat 8 image set contains the thermal constants needed to convert TIRS data to the at-satellite brightness temperature. TIRS band data is used to convert spectral radiance to brightness temperature by processing thermal constants provided in the metadata file (Table.1).

Source: Landsat 8 MTL File (Path-144, Row-053)

Table-1: Landsat 8 Metadata of the Devikulam Taluk

Metadata Details of TIRS and OLI (Landsat 8)		
Sensor	Optical Land Imager	Thermal Infrared Sensor
Date of Acquisition	2014 – 02-11	
Sun Elevation	52.64	
Path/Row	144/053	
Band	9	2
Resolution	30 m	100 m
Radiance- Mult-Band-10	:	3.3420
Radiance-Mult-Band-11	:	3.3420
Radiance-Add-Band-10	:	0.10000
Radiance-Add-Band-11	:	0.10000
K ₁ for Band 10	:	774.89
K ₁ for Band 11	:	480.89
K ₂ for Band 10	:	1321.08
K ₂ for Band 11	:	1201.14

3. RESULTS AND DISCUSSION

The Landsat 8 TIRS sensors acquire temperature data and store this information as a digital number (DN) with a range between 0 and 255. The detail step by step procedure for Land Surface Temperature (LST) calculation is given below **LST= BT/1+W*(BT/p)*ln(e)**..... Equation -1
Where:

- BT= At satellite temperature
- W=Wavelength of emitted radiance (11.5µm)
- p = h*C/S (1.438*10⁻²mK)
- h = planck’s Constant (6.626*10⁻³⁴J.S)
- s = Boltzmann Constant (1.38*10⁻²³J/K)
- C = Velocity of light (2.998 *10⁸ m/s)
- p = 14380

The first step is convert digital number to radiance using the given below formula

Lλ is the Spectral Radiance at the sensor’s aperture (watts/(m²*ster* µm))

Lλ = M_LQ_{cal} + A_L.....Equation-2

Where:

- Lλ = TOA spectral radiance (watts/(m²*ster* µm))
- M_L = Band Specific multiplicative rescaling factor from the meta

(RADIANCE _MULT_BAND_X, Where X is the band number 10 or 11)

A_L = Band specific additive rescaling factor from the metadata

(RADIANCE _ADD_BAND_X, Where X is the band number 10 or 11)

Q_{cal} = Quantized and calibrated standard product pixel values (DN)

So, Lλ for the study area is;

Lλ = 0.0003342 * Band 10 + 0.1

The same to be executed for the Band 11

From the formula we can get *Band10 Radiance and Band11Radiance* as an output.

The Second step is Convert Band radiance (which is derived from equation 2) to brightness temperature using the thermal constant given in meta data file. The conversion formula is given below

T = K₂/ln (K₁/ Lλ+1) – 272.15.....Equation-3

Where

- T= At – Satellite brightness temperature in Kelvin (K)
- Lλ = TOA spectral radiance (watts/(m²*ster* µm))
- K₁ = Band_Specific thermal conversion from the metadata (K₁ – Constant_Band_X, where X is the band number, 10 or 11)
- K₂ = Band_Specific thermal conversion from the metadata (K₂ – Constant_Band_X, where X is the band number, 10 or 11)

272.15 = Convert Kelvin to °Celcius.

According to the equation 2, T can be calculated for the study area is

$$T = 1321.08 / \ln(774.89^{Band10Radiance} + 1) - 272.15$$

The same to be executed for the Band11Radiance, where we can substitute K₊ and K₂ value for Band 11

From the formula we can get BAND10SATTEMP and BAND10SATTEMP as an output. It depicts the brightness temperature in degree celcius.

The third step is find out the average temperature of both BAND10SATTEMP and BAND10SATTEMP using the Cell statistics tool and select the mean statistics option and we can get SATTEMPBAND1011 as an output. Here the minimum temperature is 12.58°C and maximum temperature is 39.52°C

The fourth step is deriving Land Surface Emissivity (LSE).

$$e = 0.004 P_v + 0.986 \dots\dots\dots\text{Equation- 4}$$

e = Emissivity

P_v = Proportion of vegetation which is calculated using NDVI value

NDVI = Normalised Difference Vegetation Index

NDVI can be calculated in ArcGIS by applying the given formula

$$\text{Float (Band5 - Band4) / Float (Band5 + Band4)} \dots\dots\dots\text{Equation - 5}$$

Where

Band5 = Infrared Band, Band4=Red band

From the NDVI result, NDVI_{min} Value is - 0.0812195 and NDVI_{max} value is 0.60394 (Map.2). We can substitute these value in equation 4 and derive proportion of vegetation(P_v).

$$P_v = (\text{NDVI} - \text{NDVI}_{\min} / \text{NDVI}_{\max} - \text{NDVI}_{\min})^2 \dots\dots\dots\text{Equation - 6}$$

In ArcGIS it can be done by applying this formula

$$\text{Square ("NDVI" + 0.0812195 / 0.607394 - 0.0812195)}$$

Now we can get PROPVEG as an output of Proportion of vegetation. Now we can calculate LSE by applying P_v value in equation 3

$$\text{That is } 0.004 * \text{PROPVEG} + 0.986$$

Now we can get LSE of the study area which shows in map.3

The final step is calculate land surface temperature using equation 1. The output such as BAND10SATTEMP substitute for 'BT' that is brightness temperature in °c, and LSE value replaced in 'e' that is emissivity. The equation-1 is

$$LST = BT / (1 + W * (BT/p) * \ln(e))$$

In ArcGIS it can be done through this formula, i.e.

$$LST = \frac{BAND10SATTEMP}{1 + W * (BAND10SATTEMP / 14380) * \ln(LSE)}$$

Finally we can get the actual land surface temperature of band10 (LST) of the study area (Map.4). Table. 2 given the statistics of study area LST. Sun elevation 52.64 represent the time is probably the morning.

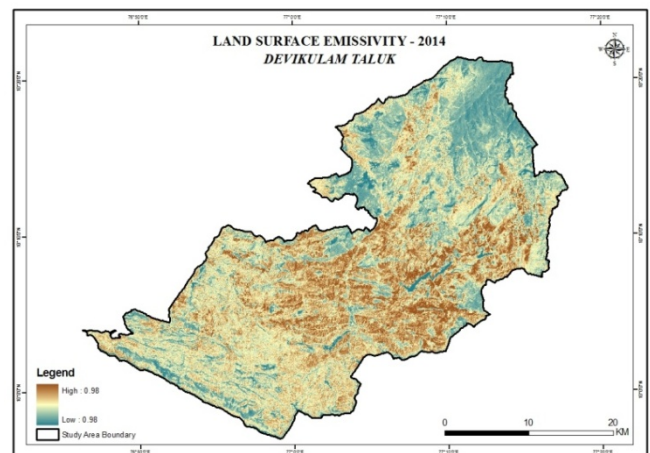


Fig-2: NDVI Map

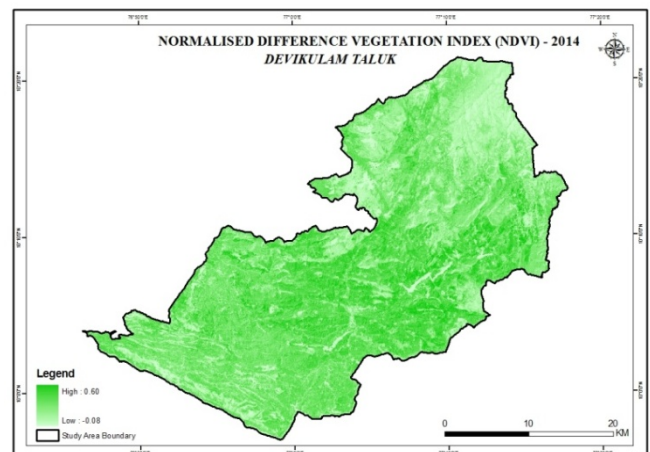


Fig-3 Land Surface Emissivity Map

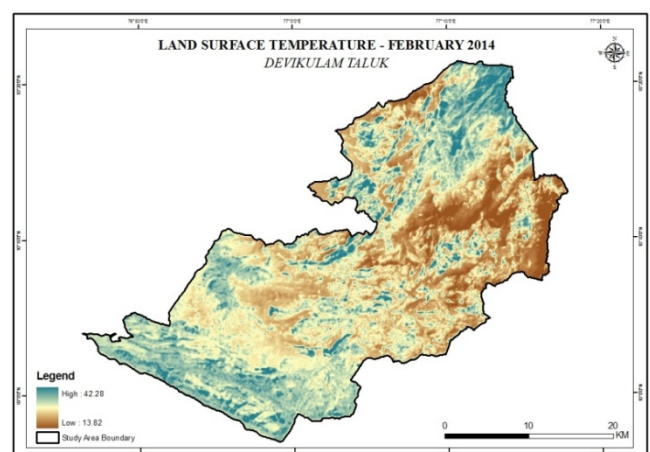


Fig-4: Land Surface Temperature Map

Table-2: Statistics of Landsat 8 LST of Devikulam Taluk

Statistics of Landsat 8 LST	
Sensor	TIRS
Minimum Temperature	14.16
Maximum Temperature	41.81
Mean Temperature	24.61
Standard Deviation	3.51

4. CONCLUSIONS

In this paper, potential of remote sensing to study the temperature variation in Devikulam Taluk by estimating LST distribution with the help of Landsat 8 OLI and TIRS sensor bands provided by the USGS with free of cost. Single window algorithm methods are applied to calculate the LST from TIRS. The heat energy radiated by the earth's surface determine factors such as different land use types, vegetation cover and soil in the study area reveals the variation in surface temperature of different surface patterns. Surface temperature variation controls the surface heat and water exchange with the atmosphere resulting climatic change in the region. Though some climatic phenomena play a minor role in temperature variation, the major role such as land conversion due to rapid tourism development, ever increasing automobile carbon emission, firewood combustion from kitchen, periodical removal of firewood for example eucalyptus and forest replaced by settlement and restaurant etc are resulting in temperature variation. Remote Sensing technology data such as Landsat 8 TIRS proved as an efficient one to estimate LST. The result help us to estimate the micro climate, heat pocket and maximum temperature vulnerable regions in the study area and also take the necessary scientific action like forestation, frequent pollution checking to the vehicles, reduced plastic incineration etc., curbs the temperature increase.

5. ACKNOWLEDGEMENT

The author highly acknowledge the financial assistance provided by the University Grants Commission's Rajiv Gandhi National Fellowship.

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