

Normalized difference vegetation index and land surface temperature evaluation of agricultural land near Ujani Dam Solapur district using TIMESAT software

Manisha Kumawat,^{1*} Arti Khaparde,¹ Mehul Pandya,² Pooja Pawar¹

¹Dr. Vishwanath Karad MIT World Peace University, Paud Road, Kothrud, Pune 411038. India. ²SAC, Indian Space Research Organization, Ahmedabad, Gujarat. India.

Received on: 05-Jul-2023, Accepted and Published on: 06-Sep-2023

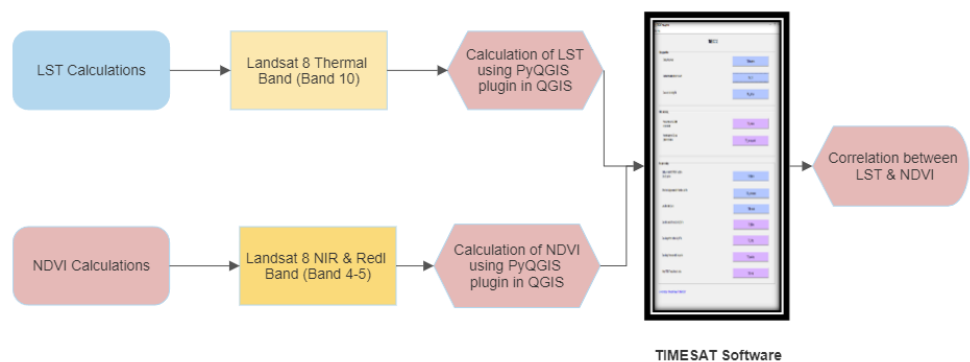
Article

ABSTRACT

The fusion of normalized difference vegetation index (NDVI) and land surface temperature (LST) provides very important information for analyzing systems such as agricultural drought monitoring system or drought early warning system. This research paper focuses on the study of the relation amongst land surface temperature and normalized difference vegetation

indices using time series composed of Landsat 8 satellite OLI/TIRS sensor data. For deriving LST, the Radiative Transfer Equation (RTE) algorithm and the Planck's function have been used with a PyQGIS plugin of Landsat 8 TIRS data. Along with LST and (NDVI), at-sensor reflectance, Land Surface Emissivity (LSE) and brightness temperature are also calculated using the PyQGIS plugin. TIMESAT software is used for estimation of phenological parameters which helps in understanding the growth of crops at different stages, effects of climate changes on crops and finding the relation between LST and NDVI. It has been observed that LST and NDVI are strongly negatively correlated. Planck's function gives the best negative correlation result as compared to the RTE algorithm. Also, various adjustment methods such as Savitzky Golay and Double Logistic Function are used for computation of seasonality parameters and it can be observed that Double logistic gives the best results.

Keywords: LST, NDVI, TIMESAT, Seasonality Parameters, RTE, Planck's function



INTRODUCTION

In India farming, with its associated sectors, is the most important source of income. Seventy per cent of rural households in India are mainly dependent on agriculture for their incomes. Also, India's population is increasing expeditiously. Its population in the next decade is expected to become the largest in the world and providing food for them will be a very key issue. India needs better management of farm practices on a number of fronts. To foster sustainable practices and to gather information about intolerable uses of natural resources, it is essential to have good quality land data sets.

A coherent and continuous set of information about the globe's oceans and land is provided by the Earth observation satellites. Remote sensing satellites visit the same location over and over again and images received from the satellites can be adjusted so that measurements taken from the same location at different times can be compared.¹

Earth Observation satellites provide images in different temporal and spatial resolutions, captured by different spectral channels. This geo-scientific data helps in providing the means to evaluate the LST. The temperature of the upper surface when the soil is bare and vegetation is LST. With development in the satellite technology and the availability of high-resolution satellite imaging, these satellite data are still the only source that can be used to measure LST across the planet. NDVI is straightforward, very effective and a widely used index of density vegetation and health thick vegetation. To achieve better accuracy and to increase its pertinence, it is recommended that NDVI should always be merged with other parameters.

*Corresponding Author: Manisha Kumawat
Email: manisha.kumawat@mitwpu.edu.in

Cite as: J. Integr. Sci. Technol., 2024, 12(2), 735.
URN:NBN:sciencein.jist.2024.v12.735



©Authors CC4-NC-ND, ScienceIN ISSN: 2321-4635
http://pubs.thesciencein.org/jist

Various vegetative indexes exist but the final choice of the index depends on the uses; however, none of them are considered intrinsically superior to the others in all situations. For some applications, certain indexes are more appropriate than others. When the LST is paired with the NDVI, it can be used to detect a region's agricultural dehydration and to keep track on vegetation, etc

This research focuses on finding relation between NDVI and LST using TIMESAT software from LANDSAT 8 data. Planck's function and RTE have been used for LST calculation.

Related Work

Data on land cover is crucial for planning conservation efforts, managing natural resources, and building the earth system. For studying land data Kumawat M. et. al. (2022)² used a new hybrid meta-heuristic technique named Adaptive Coyote Crow Search Optimization (ACCSO) along with Adaptive time-weighted Dynamic Time Warping. In order to estimate and anticipate the thermal activity, Shivam Chauhan et al. (2023)³ employed the remotely sensed land surface temperature distribution from two satellites, namely Aqua and Terra, of Jaipur city. A basic Dynamic Time warping algorithm with Deer Hunting-based Grey Wolf Optimization (DH-GWO) is utilized for static and dynamic gesture recognition by Manisha Kowdiki et. al. (2022).⁴ For the classification of land cover M. Kumawat et.al. (2022)⁵ proposed moth flame-based bird swarm optimization (MF-BSA) for enhancing the performance with Adaptive dynamic time warping. S. Huang et al. (2021)⁶ provided a summary of the development of NDVI acquisition, highlighted the areas of NDVI application, and addressed the significant issues and factors to be taken into account while utilising NDVI. The soft computing models for predicting changes in land surface temperature (LST) were utilised by Elhadi K. et.al.(2020)⁷ to assess and anticipate the world's rapidly changing climate. In this study, the best model that can be used to predict the LST changes in the Beijing area is determined by applying and comparing four soft computing techniques: wavelet neural network (WNN), adaptive neurofuzzy inference system (ANFIS), and dynamic evolving neurofuzzy inference system (DENFIS).

LST was extracted from Landsat images using RTE Allaka et al. (2019).⁸ Sruthi and Aslam (2015)⁹ observed correlation between LST and NDVI using a method dependent on view angle applied directly to data and converted to degree Celsius. Yearly land covered dynamics methodology has been used by Julien (2011)¹⁰ to analyze the behavior of vegetation from the data downloaded from the NOAA AVHRR satellite. The Split window (SW) coefficient algorithm, Improved Single channel and the Mono Window (IMW) algorithms are used in order to retrieve the LST using TIR bands.¹¹⁻¹³ Also, Ceccato et al. (2010)¹⁴ have estimated the maximum air temperatures using the MODIS data as per the diurnal cycle by the extrapolation of the minimum temperature can be derived. For avoiding the limitations of NDVI Chakraborty and Sehgal (2010)¹⁵ have used two bands in the Near Infrared (NIR) channel for the normalized difference water index calculation. For drought detection geographic information system and remote sensing techniques using Standardized Precipitation Index were used in

Murad et al. (2011).¹⁶ Guha and Govil (2020)¹⁷ have shown a relationship between LST and NDVI utilizing the Mono window algorithm (MWA) for getting LST. Arslan et al. (2016)¹⁸ have used three parameters, namely, LST, NDVI and Drought surveillance using the Vegetation Supply Water Index (VSWI). Also, Yang (2014)¹⁹ adopted a combination of the split window algorithm and Planck's radiation equation which is expanded linearly for the LST calculation. Jiménez-Muñoz (2014)²⁰ discussed Landsat-8 TIRS data that was used to apply the Spilt Window (SW) and Single Channel (SC) algorithms for LST recapture. Estimation of LST is done in ArcGIS using the NDVI. Land surface emissivity is given in Anandababu et al. (2018).²¹

All of these works used different methods to calculate LST. In some papers the relationship between NDVI and LST is established by making usage of the yearly land covered dynamics algorithm. Here the authors are also establishing the relationship between LST and NDVI, utilizing Planck's algorithm and Radiative Transfer Equation for calculation of LST. The TIMESAT software has been used for forming time series and to find the connection between LST and NDVI.

Contribution

In this paper, RTE and Planck's algorithm have been used for the measurement of LST. Then to establish the association between NDVI and LST, TIMESAT is used. Also to calculate the correlation value Pearson's Correlation Coefficient is used for LST and NDVI. Specifically, the main contributions in the paper are as follows:

Planck's function and the RTE algorithm are used to measure LST. The NDVI and LST implementation part has been executed using a Python QGIS (PyQGIS) plugin. Thermal Infrared (TIR) images from Landsat 8 are utilized to create land surface temperature contours. Then correlation is measured between two quantities for both LST retrieval algorithms.

The authors propose to use the TIMESAT software to check the relation between LST and NDVI, which is basically used for seasonality parameter extraction. TIMESAT is tested on 16-days Landsat 8 OLI/TIRS data. We have used LST as well as NDVI data as input for the TIMESAT software for calculating the relation amongst NDVI and LST. Both, the NDVI and the LST, of a given crop are studied at the same time.

DATA COLLECTION

Satellite Data

OLI/TIRS Landsat 8 data used for our work are taken from site <https://earthexplorer.usgs.gov/>. Time-Series data captured by Landsat 8 is with the frequency of 16 days. Landsat 8 supports the Operational Land Imager (OLI) and Thermal Infrared Sensor (TIRS) payloads, and this one is the most recently initiated satellite is Landsat. With 11 bands, these two payloads give recurring scope of the global landform at 100 meters (thermal), 30 meters (visible, NIR, SWIR) and 15 meters (panchromatic) spatial resolution. Landsat 8 captures 740 images every day based on the Worldwide Reference System-2 (WRS-2) path/row system. The photo size is 185 km x 180 km in dimension. Surface reflected images from 1st January 2017 to 31st December 2018 are used for this study.

The GEOTIFF format is used to obtain worldwide data. The satellite remote payloads will determine what percentage of the light is absorbed or reflected in a particular region of the spectrum. For example, green vegetation has heavy spectrum absorption for the high infrared channel and a red channel reflectance. As a result, a vegetation index is composed of different red and infrared bands. Satellite information is utilized to find seasonality parameters with the help of TIMESAT in MATLAB and measure LST using PyQGIS in QGIS.

Location/ Study area

The study location is an agricultural land near Ujani dam, Solapur district, Maharashtra, India as shown in Fig. 1. One location using the geographic coordinate system is considered from the same farm with latitude and longitude coordinates, 18.142369N, 75.219999E.



Figure 1: Study Location

SOFTWARE

Remotely sensed time series data contains a lot many information so as to investigate and derive desired results from such data sets; GIS and various other software are used. TIMESAT in MATLAB and the PyQGIS plugin in QGIS software are used for obtaining vegetation index time- series data derived from satellite spectral measurements, which are applicable in extracting details on seasonal vegetation development.

Timesat

Seasonal vegetation growth can be measured using a vegetation index time series data gathered from spectral measurements of space satellite. The TIMESAT programme package was created to explore and extract phenological parameters from data time series. The TIMESAT 3.3 version includes many time-series data smoothing methods as well as outlier detection methods. It produces 13 repetitive parameters which we can use to find the phenological matrices.^{22,23}

The key phenological metrics like the beginning and end of the rising season, duration of one crop cycle, asymmetry cycle, etc. can be extracted for each image pixel. The final method preference is determined by how fine the fitted functions match the original data, and input data as well. TIMESAT comes with an accumulation of script files of MATLAB which can be utilized to present the raw information as well as the equipped functions.

QGIS

QGIS is a quantum geographic information system programme which permits access, editing and it analyzes geospatial data on desktop for free. In QGIS 2.8.8 the LST estimation plugin (PyQGIS) can be added easily.²⁴ The Python programming language is used to create PyQGIS. Research is being carried out

using an open source tool uses Landsat 8 TIRS data and permits development of LST maps, Landsat 5 TM and Landsat 7 ETM+. The plugin was created to make the production of LST from Landsat Visible, Near Infrared (VNIR), and Thermal Infrared (TIR) imagery data easier. Through the PyQGIS plugin the Planck’s function, the MWA, the Single Channel Algorithm (SCA) and the RTE, it is possible to calculate Land Surface Emissivity (LSE), to estimate at-sensor radiance, to estimate the brightness temperature, and apply brightness modification against atmospheric interference. This plugin is available on the official QGIS repository for download and can be utilized by Landsat sensor users.

METHODOLOGY

The first step is to download Landsat 8 L2 level surface reflected images. After this, it is possible to apply steps of the LST calculations. Steps to calculate LST, formation of time series and to give input to TIMESAT are as given in Fig. 2.

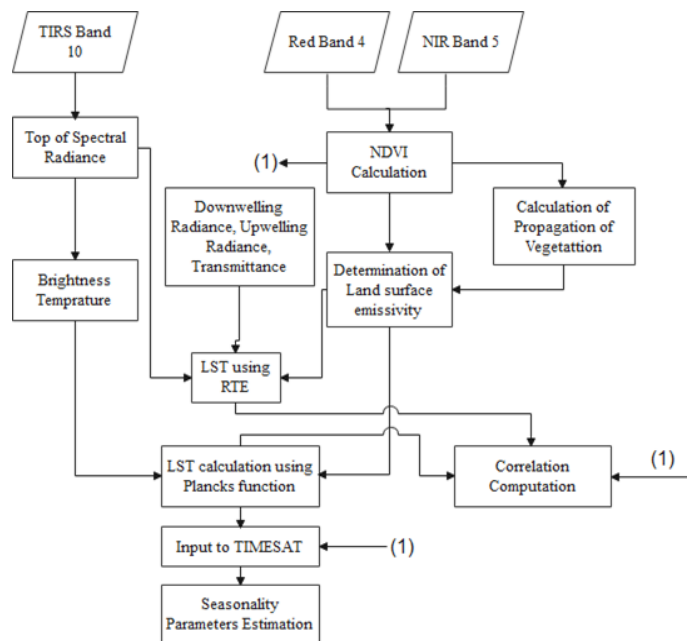


Figure 2: Flow Chart of Methodology

Top of Atmosphere Spectral Radiation Calculation

Pixel values are used for storing the thermic information of Landsat sensor imagery from the space station. It is a method of showing pixels those yet have not been converted into significant units. These are raster image representations of various intensities of electromagnetic energies. The method begins with the transformation of pixel values also known as Digital Number (DN) to radiance after the satellite images have been prevailed. The Landsat 8 TIRS sensor uses equation (1) to transform DN to spectral illumination Ndossi and Avdan (2016).

$$TOA = M_L * B_{10} + A_L - O_i \quad \text{in } W/m^2/sr/\mu m \quad (1)$$

Where,

ML - Landsat-8 particular factor of multiplication for 10th band

AL - Landsat-8 specific additive factor for 10th band

B10 - Estimated and calibrated product pixel values

O_i - USGS has issued Offsets for the tuning of the TIRS bands.

USGS scientific agency provides O_i offset calibration. A -0.29 value was used as an adjustment factor for band 10, Landsat 8 TIRS.²⁵ To adjust the radiances of Landsat 8's band 10, these values are subtracted from the radiances. The Landsat 8 TIRS payload has two Thermal Infrared (TIR) bands as there is uncertainty in band 11 values. Due to this at the moment, only band 10 data is suitable for LST extraction. Figure 3 gives the application interface for converting pixel values to radiance values.

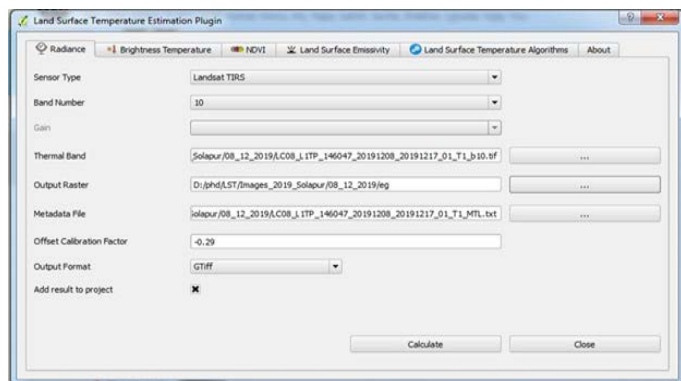


Figure 3: Application of Interface for calculation of TOA Radiance

Brightness Temperature (BT) Calculation

After the pixel values have been transformed into radiance, the second move is to convert the highest of the atmosphere spectral radiance into radiance temperature. Radiance heat also known as BT is the blackbody temperature of thermal equilibrium with the environment. The following equation 2 translates the radiance to BT.

$$BT = \frac{K_2}{\ln\left(\frac{K_1}{TOA} + 1\right)} \text{ in Kelvin} \quad (2)$$

Where,

K₁ - Constant of thermal conversion Landsat-8 for 10th channel

K₂ - Constant of thermal conversion Landsat-8 for 10th channel

K₁ and K₂ values depend upon the payloads and the thermal channel wavelengths by which it work and it may vary after a change in the payload or wavelength. The values of K₁ and K₂ are given under the metadata file of an image for a particular date. Fig. 4 gives the application interface of calculating the BT and converting TOA radiance to the BT. The window is reached through the "Brightness Temperature" option of a PyQGIS plugin.²⁶

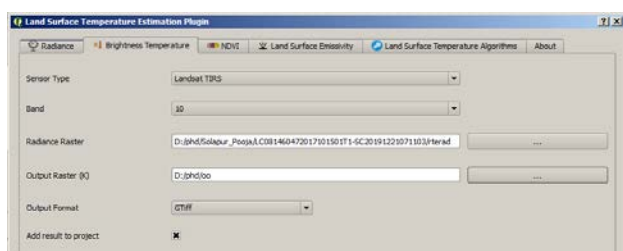


Figure 4: Application of Interface for calculation of Brightness Temperature

NDVI Calculation

NDVI measure the difference between near-infrared (which vegetation strongly reflects) and red light (which vegetation strongly absorbs), also which measures vegetation. For calculation of greenness on the earth's and emissivity surface 4-th (B4) Red and 5-th near infrared (B5) bands can be used out of the Landsat-8 multispectral bands. Computation of NDVI is as given below in Equation 3). A proportion of vegetation (P_v) is to be estimated which is required for land surface emissivity calculation.

$$NDVI = \frac{\text{band 5} - \text{band 4}}{\text{band 5} + \text{band 4}} \quad (3)$$

Where,

Red – radiance in red channel or band B4

NIR – radiance in Near Infra-Red channel or band B5

Fig. 5 shows the application interface for getting Normalized Difference Vegetation which will be further required for calculation propagation of vegetation and land surface temperature measurement.

NDVI is always in the range of -1 to +1. When the readings approach -1, its most likely water. When the NDVI is near to zero, however, green leaves are absent, indicating that the region is urbanized. If the NDVI number is near to +1, however, there is a good chance that the vegetation is healthy (chlorophyll). When compared to other bands, dense forest radiates more in near-infrared (NIR) and green bands. Dense forest does, however, absorb more in red band and blue light band. A more NDVI value is obtained when the red channel has minimum reflectance (or low values) and the NIR band has high reflectance. Overall, NDVI is a standardized method of determining the health of plants. A NDVI high values show that there is more nutritious plants; whereas NDVI low values shows that there is less or no vegetation.

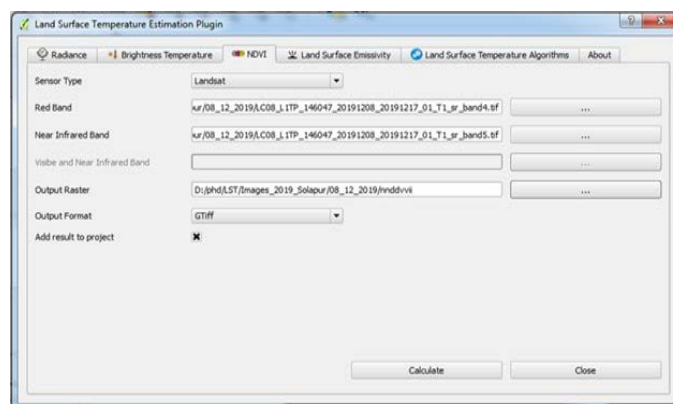


Figure 5: Application of Interface for calculation NDVI

As per Equation (4) the proportion of vegetation is measured using bare land vegetation (NDVib) and stable plant vegetation NDVip Avdan and Jovanovska (2016). Constants may be used to have these values (NDVib = 0.2 and NDVip =0.5) or may be derived from an image. While computing these attributes from the data the maximum is represented by NDVip. The NDVI minimum does not always correspond to a specific class of bare ground; it may be data related to water bodies. So, it is very complex to find the value of NDVib. As a result, certain threshold points or

classification maps are always required for the accurate identification of this value.

$$P_v = \left(\frac{NDVI - NDVI_b}{NDVI_p - NDVI_b} \right)^2 \quad (4)$$

Where,

NDVI_p- Vegetation of healthy plants value

NDVI_b - Bare land vegetation value

Computation of Land surface emissivity (LSE):

The action of an object’s ability to release infrared energy is known as emissivity. Released energy indicates the temperature of the location. Emissivity values can vary from 0 (shiny mirror) to 1.0 (blackbody). Many oxidized surfaces, organic or painted objects can have emissivity values near to 0.95. Land surface emissivity is required to calculate LST using Planck’s function and RTE and it can be calculated using Equation (5).

$$\varepsilon = \varepsilon_v * P_v + \varepsilon_s (1 - P_v) + C \quad (5)$$

In which,

ε_v - Emissivity of Vegetative ($\varepsilon_v = 0.973$)

ε_s - Bare soil emissivity values ($\varepsilon_s = 0.966$)

C - Roughness of the Surface (for plain surface C = 0)

As per Zhang’s algorithm, estimation of LSE can be possible if the NDVI for an area is known Ndossi and Avdan (2016). Estimation of LSE for a particular pixel is done by classification of the pixels as per the class under which they fall. The 0.995 LSE value will be allotted a particular pixel location and when the NDVI data of a pixel is less than -0.185. The pixel is given an LSE data of 0.985 when the NDVI value is more than or equal to 0.185 but less than 0.157. When the NDVI value is more than or equal to 0.157 but less than or equal to 0.727, a logarithmic relationship between LSE and NDVI is used. When the NDVI data exceeds 0.727, the location is permanently given a value of 0.990 as per in Table 1.

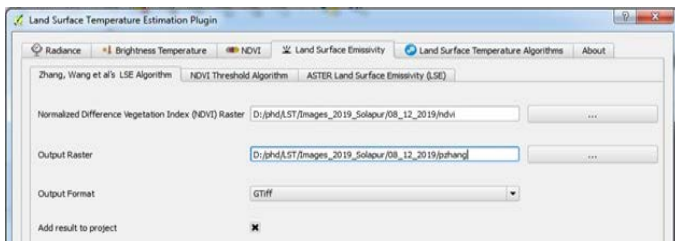


Figure 6: Land Surface Emissivity calculation Application of Interface (Using Zhang’s algorithm)

Fig. 6 shows the LSE estimation programme interface of the plugin. It can be accessed through “Land Surface Emissivity tab” option in the estimation plugin. It is calculated with the help of NDVI which is calculated in the previous step.

Table 1: NDVI images based Algorithm

Greenness value	LSE
NDVI ≤ -.1850	.9950
-.1850 ≤ NDVI ≤ .1570	.9850
.1570 ≤ NDVI ≤ .727	1.009 + .0470 * log(NDVI)
NDVI > .7270	.9900

Table 2: Values of LSE for various terrene substances

Terrene Material	Vegetation	Water	Ground	Build-up area
Emissivity	0.9660	0.9620	0.9730	0.9910

Land Surface Temperature Calculation:

It is always necessary to rectify parameters of the atmosphere and brightness temperature vs. LSE. Numerous mechanisms are available for thermal infrared satellite imagery, which is designed for the purpose of estimation of LST. The type of algorithms may change from one sensor to the next sensor and every algorithm has its differences, restrictions and strength in the degree of precision. In this research, one algorithm has been executed using the LST estimation plugin.²⁶ The algorithm used for LST calculation is the Inversion Planck’s Function algorithm.

Equation (6) is used for calculation of the LST either into Kelvin or Celsius.

$$LST = \frac{BT}{1 + \frac{BT}{\lambda * \rho}} * \ln(\varepsilon) \quad \text{in Kelvin} \quad (6)$$

$$\rho = h * c = 1.438 * 10^{-2} \text{m}$$

Where,

λ - Emitted radiance wavelength

$\lambda = 10.892$ Thermal band 10 For Landsat 8

ε - A spectral emissivity

σ - Boltzmann constant c - Light velocity

h - Planck’s constant

Fig. 7 shows the application or the purpose of calculating the LST using the Plank’s function in the plugin. “Land Surface Temperature Algorithm tab using Planck’s function” option is reached through the estimation plugin. For estimation of the LST, brightness temperature and LSE are needed, which are already calculated in the previous steps.

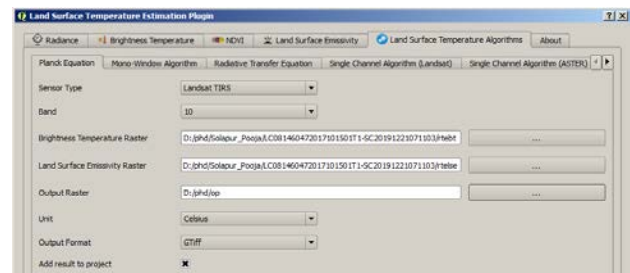


Figure 7: Application of Interface for calculation Land Surface Temperature using planks function

Radiative Transfer Equation Calculation

Down-welling radiance and Up-welling Radiance Estimation, Transmittance of Atmosphere:²⁵

The Atmospheric Correction Parameter Calculator of NASA was used to estimate atmospheric parameters such as transmittance, up-welling, and down-welling radiance of Landsat 8 TIRS in this analysis. Parameters are calculated using <https://atmcorr.gsfc.nasa.gov/>. It uses date; time and the longitude latitude coordinate location as inputs. A few samples of the

obtained, Atmospheric Transmittance, down welling radiance and up welling radiance are shown in Table 3.

Table 3: Atmospheric Sample Parameters

Payload	Day	Timing (GTM)	Atmospheric Up welling Radiance Transmittance W/(m ² .sr.um)	Down welling Radiance W/(m ² .sr.um)
Landsat	2017.10.	5.22	0.79	2.66
8	31		1.62	
Landsat	2017-11-	5.22	0.77	2.91
8	16		1.80	

Thermal infrared radiance of the satellite sensor is calculated using Equation (7):

$$L\lambda = (\epsilon\lambda L\lambda (Ts) + (1 - \epsilon\lambda) L\lambda_{down}) \tau + L\lambda\mu p \tag{7}$$

In which,

$L\lambda$ – Down welling radiance, up welling radiance and Atmosphere transmittance surface radiance are three forms of thermal infrared radiances acquired by satellite sensors.

τ - Values of Atmospheric transmittance,

ϵ – LSE Value

$L\lambda (Ts)$ - Kinetic temperature T_s of black body for required Radiance

$L\lambda\mu p$ - Atmospheric path radiance or up-welling

$L\lambda_{down}$ - Sky radiance or down-welling.

Dynamical temperature $L (Ts)$ of land surface radiance T_s is determined by utilizing (8)

$$L\lambda(T_s) = \frac{L\lambda - L\lambda\mu p}{\epsilon\lambda\tau} - \frac{1 - \epsilon\lambda}{\epsilon\lambda} L\lambda_{down} \tag{8}$$

Equation (9) converts radiance measurements to LST by employing two prelaunch calibration constants, K_1 and K_2 . These values can be seen in the metadata file which comes along with the images.

$$T_s = \frac{K_2}{\ln\left(\frac{K_1}{L\lambda(T_s)} + 1\right)} \tag{9}$$

Fig. 8 demonstrates the Radiative Transfer Equation algorithm's application interface

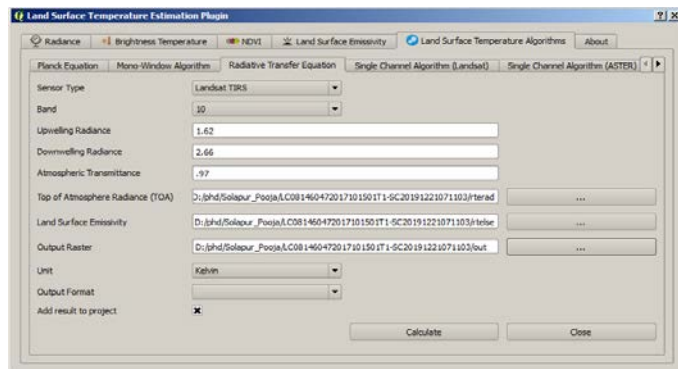


Figure 8: Radiative Transfer Equation Application Interface

Construction of Time Series

NDVI/LST data is available as an image format calculated using the previous steps given in the methodology section. Each of the NDVI/LST image I is arranged in an array format for a defined time period t . By obtaining LST/NDVI data from a time-series at position (j, k) , an array of consecutive periods (t_i, I_i) , $S = I_1, I_2, I_3 \dots I_N$ is obtained for this position as shown in Fig. 9.

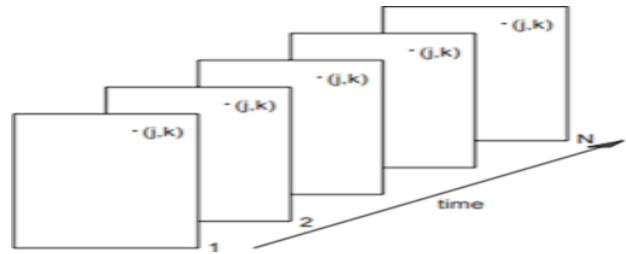


Figure 9: NDVI/LST images organized as a time series.

Each image shows NDVI data at time t . NDVI values at a given spatial location (j,k) over time; a time-series (t_i, I_i) , $S = I_1, I_2, I_3 \dots I_N$ of NDVI/LST data is obtained for this position Jönsson and Eklundh (2004).

Let $S = I_1, I_2, I_3 \dots I_N$ be a set of N images with width W and height H i.e., S is a data set generated by combining image time series. Equation (10) provides information about how the time series is constructed from a sequence of photographs.

$$S = ((I_1(j, k), I_2(j, k), \dots, I_N(j, k)) \mid j \in [1, W], k \in [1, H]) \tag{10}$$

By using the same method two separate time series are formed, namely, S_1 for NDVI and S_2 for LST. This data is further used as input to TIMESAT and is also used for finding the correlation coefficient.

Correlation Computation

Correlation coefficient is used to show how strongly pairs of LST and NDVI variables are associated to each other.⁹ It can be seen that the two sets of data have a high correlation because they are closely related. When two values increase in tandem, the correlation is positive; when one value declines as the other increases, the correlation is negative. Equation (11) shows Pearson's coefficient (also known as Pearson's R). In linear regression, this is a correlation coefficient that is a widely used approach to model the relationship between two variables. LST values are calculated using Planck's function and the RTE algorithm.

Correlation can have a value:

Positive Correlation – one or value towards one.

No Correlation – 0 value (The principles don't seem to be linked in any way.)

Negative Correlation – -1 or value towards -1

$$r_{LST,NDVI} = \frac{\sum_{i=1}^n (LST_i - \overline{LST})(NDVI_i - \overline{NDVI})}{\sqrt{\sum_{i=1}^n (LST_i - \overline{LST})^2 \sum_{i=1}^n (NDVI_i - \overline{NDVI})^2}} \tag{11}$$

n - No. of samples / dates considered for study i.e., for two years of data.

Sequential Data File preparation

Using NDVI and LST time series data, sequential data files are prepared which are also known as ASCII files.²⁷ A collection of time series stored as a text document also known as an ASCII file processed by the TIMESAT software. The header line of an ASCII file contains particulars concerning the count for years passed over by means of time series nyear, the complete amount of information points collected in a year, which is nptperyear, and the total amount of time-series that the ASCII file considers, which is, nts. The different time series values are shown line by line after the header row for generalized data. Organization of the data in the ASCII file containing the time series is given below in Equation (12).

nyear nptperyear nts

$$nts \begin{cases} y_1 & y_2 & \dots & y_N \\ y_1 & y_2 & \dots & y_N \\ y_1 & y_2 & \dots & y_N \end{cases} \quad (12)$$

Where,

nyear - Number of years considered for study nptperyear- Total count of samples neveryear

nts - Number of time series used

The TIMESAT programme collection is fundamentally planned for examining data from satellites over time. It uses an adaptive Savitzky-Golay fitting algorithm along with other algorithms depending on the upper envelope weighting fitting function with many methods which are assigned various weights for time-series details such as Double Logistic Model Functions and asymmetric Gaussian, etc.²⁷

TIMESAT is made up of a set of MATLAB-based numerical and graphical routines. It is commonly executed from MATLAB. Some features of TIMESAT are as follows²⁷

1. For detection of outliers, several methods are available.
2. Quality information is used for weighting of data.
3. The data can be fitted to the upper envelope.
4. For defining the start and end of a phenological cycle two methods are available.
5. Adjustable graphical user interface (GUI).
6. Executes even though MATLAB is mounted or not on the system.
7. Used with Linux and Windows operating system.
8. Huge data sets can be handled with parallel processing.

Fitting methods used

Filters are used to smooth the data. TIMESAT provides various filters out of which Savitzky Golay and Double Logistic functions are described below²⁷

Savitzky Golay Fitting Method

In Savitzky Golay, every point data $y_i, i = 1; \dots; n$, is replaced with a linear combination of neighboring window data as seen below (13):

$$\sum_{j=-n}^n c_j y_{i+j} \quad (13)$$

Where,

$$c_j = \frac{1}{2n + 1}$$

To preserve all data values, for every point data y_i where $i = 1, 2, 3 \dots \dots n$. To all $2n + 1$ data it fits a in the travelling window, the quadratic polynomial $f(t) = c_1 + c_2t + c_3t^2$ substitutes the value y_i with polynomial values at location t_i . This process is known as the Savitzky-Golay filter.

Double Logistic method:

The data is fitted to the local model functions at intervals all throughout the maximum and minimum data in the time series. The regional function given by,

$$f(t) = f(t, c, x) = c_1 + c_2 g(t, x)$$

In which,

Linear Parameters that $c = (c_1; c_2)$ measure an amplitude for starting point. The non-linear parameters $x = (x_1, x_2 \dots, x_p)$ determines the basis function $g(t, x)$ shape.

And the basis function is given by Equation (14):

$$g(t, x_1, x_2 \dots x_4) = \frac{1}{1 + \exp(\frac{x_1 - t}{x_2})} - \frac{1}{1 + \exp(\frac{x_3 - t}{x_4})} \quad (14)$$

RESULTS

In TIMESAT the menu system under TSM_GUI needs an ASCII data file as input. There are two such text files; the first provides data on land surface temperatures, while the second provides data on normalized difference vegetation indexes. The first row of ASCII data file shows the details of the data i.e., no of years for which data is taken, no. of observations in a year and no of time-series. Different fitting methods are available in TSM_GUI like Double logistic function, Savitzky Golay, Asymmetric Gaussian and STL/Trend analysis. Phenological parameters are displayed for every of the defined cycle in the TSM_GUI. For this study the authors have considered one phenological cycle of Sorghum crop (Jowar) sown on agricultural land located near Ujani dam, Solapur district. Seasonality parameters for the defined seasons have been calculated using the Double logistic fitting function and the Savitzky Golay function. As given in Fig. 10, LST data is given as input and the Double logistic fitting function is used. Based on the output data, it is possible to calculate the day of the season when LST is the maximum.

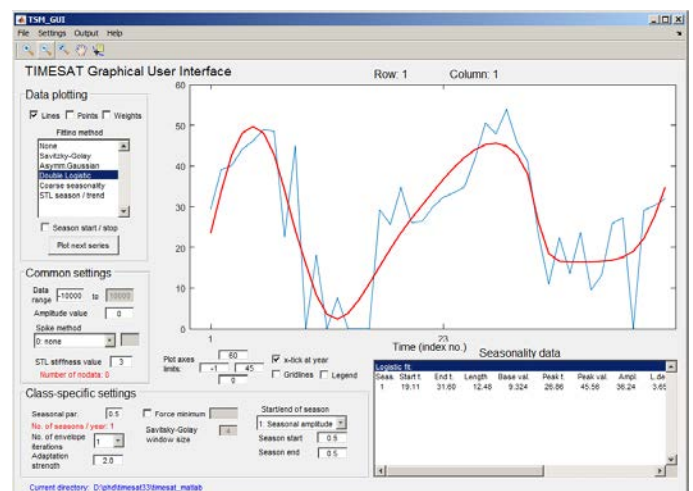


Figure 10: TSM_GUI showing LST using Double Logistic Fitting Function

Table 4 shows the analysis of LST using the Double Logistic fitting function. The maximum LST value is observed on 5th March 2018 and it is equal to 45.56 degree Celsius which is after the senescence of Sorghum (Jowar) crop. However, the land surface temperature prior to that was low when NDVI values were more.

Table 4: Analysis of LST data using Double Logistic Fitting method

Parameter	Value	Explanation
Peak time	26.86	05 March 2018
Peak temperature val.	45.56	Maximum LST

Seasonality parameters for the defined seasons have been displayed using the Double logistic fitting function as given in Fig. 11 using NDVI data.

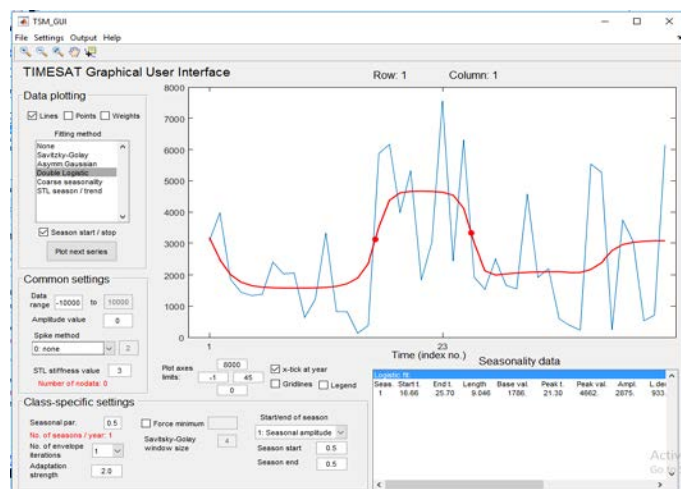


Figure 11: TSM_GUI showing NDVI with Double Logistic Fitting function

By using TIMESAT, 13 Seasonality parameters are estimated and some important parameters are given in Table 5 like the beginning of a crop cycle, the conclusion of a crop cycle, the duration of one phenological cycle in one day i.e., time from beginning of a crop cycle to the conclusion of a crop cycle, the highest time when NDVI data is maximum and the maximum value of NDVI

Table 5: Analysis of NDVI data using Double Logistic Fitting method

Parameter	Value	Explanation
Start of Season	16.66	08 October 2017
End time	25.70	02 March 2018
Length	9.046	145 days
Peak time	21.30	21 December 2017
Peak value	0.46	Maximum NDVI

Figure 12 shows the flow chart of the method for extraction of phenological parameters.

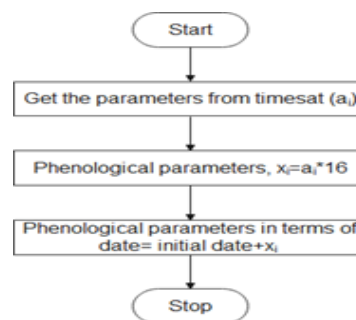


Figure 12: Flow chart for extraction of Phenological parameters

A filtered graph of LST values in TIMESAT using the Savitzky Golay fitting method along with the parameters from which we can calculate the maximum LST time is shown in Fig. 13.

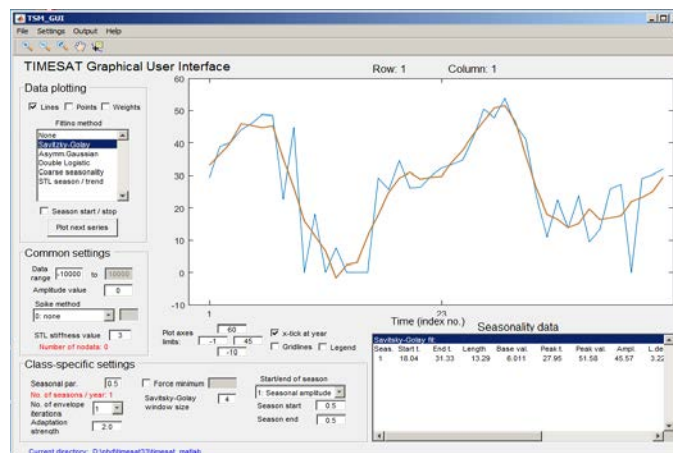


Figure 13: TSM_GUI showing LST with Savitzky Golay

In Table 6 an analysis of LST data using the Savitzky Golay Fitting method is given which shows the peak temperature value i.e. 39.36°C on the 19th February 2018. Its value in TIMESAT is 25.96°C. The value of LST starts increasing when aging of crop starts i.e., it goes towards senescence.

Table 6: Analysis of LST data using Savitzky Golay Fitting method

Parameter	Value	Explanation
Peak time	25.96	19 February 2018
Peak Temperature value	39.36	Maximum LST

A filtered graph of NDVI values in TIMESAT using the Savitzky Golay fitting function along with the parameters from which the phenological matrices have been calculated is shown in Figure 14.

Table 7 gives an analysis of seasonality parameters based on the estimation process using the Savitzky Golay function in TSM_GUI. The overall observation from the results is that the season started in the 1st week of October 2017 and ended in the 1st week of March 2018. During entire duration of one phenological cycle the land surface temperature is analyzed along with NDVI and it has been observed from the graphs that at the start of the season LST values were higher, but NDVI values were lower. At the peak period

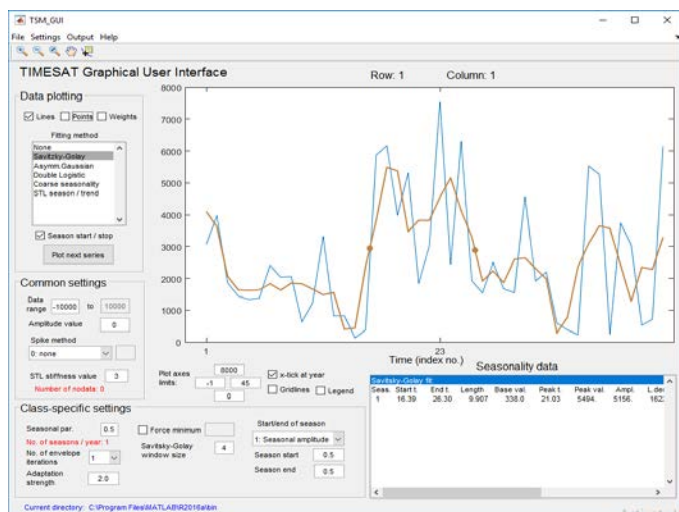


Figure 14: TSM_GUI showing NDVI with Savitzky Golay

NDVI values were higher but LST values were lower. After the peak period the NDVI values started decreasing and LST values started increasing. After the end of the season when the NDVI values were very low, the LST values were at their highest. The seasonality parameters obtained using TIMESAT are verified in situ.

Table 7: Analysis for NDVI using Savitzky Golay Fitting Function

Parameter	Seasonality Parameter	Phenological matrices
Start time	16.39	04 October 2017
End time	26.30	11 March 2018
Length	9.907	158 days
Peak time	21.03	17 December 2017
Peak value	5494	Maximum NDVI

The crop was sown around 7th October 2017 and harvested around 3rd March 2018. This information was received during a field survey and discussion with the owner of the land who cultivated this crop. Better results are obtained with the Double logistic fitting function as the start of the season was 8th October 2017 and the crop was harvested around 3rd March 2018.

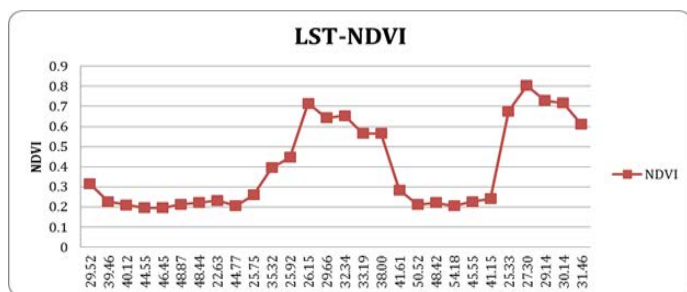


Figure 15: LST and NDVI for location (18.142369N, 75.219999E)

The graph of the relation between LST and NDVI data is plotted as shown in Figure 15. It is observed that when NDVI is the highest, LST is the lowest and when NDVI is the lowest, LST is the highest.

Here LST is calculated using Planck's function. The correlation between the LST and the NDVI is calculated at 0.31298687, which is highly negative.

For the calculation of LST in land surface temperature estimation plugin, the RTE function is used. Correlation is found between the LST and the NDVI with a value of -0.07673, which is a negative correlation as well.

It has been clearly observed in this case that the results with Planck's function are better as compared to the RTE algorithm. Planck's gives more negative correlation values as compared to the RTE algorithm.

DISCUSSION

In this paper its clearly explained how agricultural drought assessment and vegetation monitoring can be done using satellite remote sensing technology. The green cover development and vegetation senescence are determined using the NDVI. The LST can be used to monitor vegetation, identify areas that are experiencing agricultural drought, and more so when paired with the NDVI. The QGIS software with PyQGIS plugin has been used for implementing NDVI and LST. Calculated NDVI has been given to TIMESAT software in order to study different phenological parameters, and for the same location and time LST parameters are studied. It is observed that a highly negative correlation is obtained between LST and NDVI. Along with LST & NDVI, LSE, at-sensor radiance and brightness temperature are also calculated. In this study high spatial resolution 56m Landsat 8 satellite images are used whereas earlier study was done on low resolution MODIS and sentinel images. NDVI were combined with other parameter like precipitation index (Standardized Precipitation index SPI). SPI and NDVI shares strong correlation between them. The combination of SPI & NDVI works fine where water is a major concern for plant growth. It may not be suitable for dense forest areas. So, it is always recommended to combine with other parameters and study with high spatial and temporal resolution.

CONCLUSION

In this study, for monitoring vegetation and determining farming paucity, satellite remote sensing technology is used. NDVI is used to calculate green cover evolution and senesce of vegetation. Due to the calculation of NDVI being simple, It is widely utilized for regional and worldwide vegetation investigations. We have merged NDVI with other parameters which give better results and increase its accuracy. LST is combined with the NDVI and the combination is used to detect various agricultural applications like drought, soil moisture of a region, vegetation monitoring, etc. QGIS software with the PyQGIS plugin has been used to calculate NDVI and LST images for all dates. The correlation amongst NDVI and LST is calculated, and the value derived is a highly negative correlation value. The LST is calculated with RTE and the Planck's function algorithm. In comparison to RTE, Planck's function produced the best correlation values.

By giving LST and NDVI values as input to TIMESAT seasonality parameters are obtained, resulting in phenological matrices which help to understand the vegetation cover. TIMESAT provides different fitting functions like asymmetric Gaussians,

Adaptive Savitzky- Golay filtering, double logistic functions, etc. which are useful for removing noisy satellite data from the time-series. In our case the double logistic function and the Savitzky Golay fitting function are used; the double logistic function gives the best results as compares to other fitting functions.

Also, from the values of NDVI and LST that are calculated, it can be seen that when the value of NDVI is at its peak level, LST has a considerably low value. That means that when the vegetation is higher, LST is lower and when LST is higher, vegetation is lower. Thus, further it can be concluded that a very strong negative correlation exists amongst the NDVI and LST. Results can be further useful for crop forecasting application.

Acknowledgement: The authors appreciate the support of the Department of Electronics & Communication Engineering, MIT world peace University, Pune, and ISRO, SAC, Ahmedabad.

Ethics approval: The submitted work is original and has not been published elsewhere in any form or language.

Disclosure of potential conflicts of interest:

There is no potential conflict of interest.

Research involving Human Participants and/or Animals: NA

Author Contribution Statement: All authors contributed equally.

REFERENCES

- V. Maus, G. C amara, R. Cartaxo, et al. A Time-Weighted Dynamic Time Warping Method for Land-Use and Land-Cover Mapping. *IEEE J. Sel. Top. Appl. Earth Obs. Remote Sens.* **2016**, 9 (8), 3729–3739.
- M. Kumawat, A. Khaparde. Time-Variant Satellite Vegetation Classification Enabled by Hybrid Metaheuristic-Based Adaptive Time-Weighted Dynamic Time Warping. *Int. J. Image Graph.* **2022**, 2450016.
- S. Chauhan, A.S. Jethoo, U.K. Das. Duo Satellite Based Surface Temperature Comparative Study of Jaipur City Using Soft Computing. In *11th International Conference on Internet of Everything, Microwave Engineering, Communication and Networks, IEMECON 2023*; **2023**; pp 1–5.
- M. Kowdiki, A. Khaparde. Algorithmic Analysis on Deer Hunting-based Grey Wolf for Dynamic Time Wrapping-based Hand Gesture Recognition. In *2022 International Conference for Advancement in Technology, ICONAT 2022*; **2022**.
- M. Kumawat, A. Khaparde. Development of Adaptive Time-Weighted Dynamic Time Warping for Time Series Vegetation Classification Using Satellite Images in Solapur District. *Comput. J.* **2022**.
- S. Huang, L. Tang, J.P. Hupy, Y. Wang, G. Shao. A commentary review on the use of normalized difference vegetation index (NDVI) in the era of popular remote sensing. *J. For. Res.* **2021**, 32 (1), 1–6.
- E.K. Mustafa, Y. Co, G. Liu, et al. Study for Predicting Land Surface Temperature (LST) Using Landsat Data: A Comparison of Four Algorithms. *Adv. Civ. Eng.* **2020**, 2020, 16.
- L. Allaka, N. Gupta, B.H. Aithal. Land use pattern analysis and Land Surface Temperature extraction: A case study of Kolkata. In *2019 IEEE 16th India Council International Conference, INDICON 2019 - Symposium Proceedings*; **2019**.
- S. Sruthi, M.A.M. Aslam. Agricultural Drought Analysis Using the NDVI and Land Surface Temperature Data; a Case Study of Raichur District. *Aquat. Procedia* **2015**, 4, 1258–1264.
- Y. Julien, J.A. Sobrino, C. Mattar, et al. Temporal analysis of normalized difference vegetation index (NDVI) and land surface temperature (LST) parameters to detect changes in the Iberian land cover between 1981 and 2001. *Int. J. Remote Sens.* **2011**, 32 (7), 2057–2068.
- J.C. Jim enez-Mu oz, J.A. Sobrino. Split-window coefficients for land surface temperature retrieval from low-resolution thermal infrared sensors. *IEEE Geosci. Remote Sens. Lett.* **2008**, 5 (4), 806–809.
- J.C. Jim enez-Mu oz, J.A. Sobrino. A single-channel algorithm for land-surface temperature retrieval from ASTER data. *IEEE Geosci. Remote Sens. Lett.* **2010**, 7 (1), 176–179.
- F. Wang, Z. Qin, C. Song, et al. An improved mono-window algorithm for land surface temperature retrieval from landsat 8 thermal infrared sensor data. *Remote Sens.* **2015**, 7 (4), 4268–4289.
- P. Ceccato, C. Vancutsem, M. Temimi. Monitoring air and Land Surface Temperatures from remotely sensed data for climate-human health applications. *Int. Geosci. Remote Sens. Symp.* **2010**, 178–180.
- A. Chakraborty, V.K. Sehgal. Assessment of Agricultural Drought Using MODIS Derived Normalized Difference Water Index. *Icar Res. Data Repos. Knowl. Manag.* **2010**, 10, 28–36.
- H. Murad. Agricultural and Meteorological Drought Assessment Using Remote Sensing and Gis in North-West Region of Bangladesh. In *Proceedings of the 3rd International Conference on Water & Flood Management 2011*; **2010**.
- S. Guha, H. Govil. An assessment on the relationship between land surface temperature and normalized difference vegetation index. *Environ. Dev. Sustain.* **2021**, 23 (2), 1944–1963.
- M. Arslan, R. Zahid, B. Ghauri. Assessing the occurrence of drought based on NDVI, LST and rainfall pattern during 2010-2014. *Int. Geosci. Remote Sens. Symp.* **2016**, 2016-November, 4233–4236.
- L. Yang, Y.G. Cao, X.H. Zhu, et al. Land surface temperature retrieval for arid regions based on Landsat-8 TIRS data: A case study in Shihezi, Northwest China. *J. Arid Land* **2014**, 6 (6), 704–716.
- J.C. Jimenez-Munoz, J.A. Sobrino, D. Skokovic, C. Mattar, J. Cristobal. Land surface temperature retrieval methods from landsat-8 thermal infrared sensor data. *IEEE Geosci. Remote Sens. Lett.* **2014**, 11 (10), 1840–1843.
- J.B. DE JESUS, I.D.M. SANTANA. Estimation of Land Surface Temperature in Caatinga Area Using Landsat 8 Data. *J. Hyperspectral Remote Sens.* **2017**, 7 (3), 150.
- P. J onsson, L. Eklundh. TIMESAT - A program for analyzing time-series of satellite sensor data. *Comput. Geosci.* **2004**, 30 (8), 833–845.
- L. Eklundh, P. J onsson. TIMESAT 3.3 software manual. Sweden.
- R.R.N. Kanapaka, R.K. Neelisetti. A survey of tools for visualizing geo spatial data. In *2015 International Conference on Control Instrumentation Communication and Computational Technologies, ICCICT 2015*; **2016**; pp 22–27.
- M.I. Ndossi, U. Avdan. Application of open source coding technologies in the production of Land Surface Temperature (LST) maps from Landsat: A PyQGIS plugin. *Remote Sens.* **2016**, 8 (5), 413–413.
- L. Shumilo, B. Yailymov, N. Kussul, et al. Rivne City Land Cover and Land Surface Temperature Analysis Using Remote Sensing Data. *2019 IEEE 39th Int. Conf. Electron. Nanotechnology, ELNANO 2019 - Proc.* **2019**, 813–816.
- L. Eklundh, P. J onsson. TIMESAT: A Software Package for Time-Series Processing and Assessment of Vegetation Dynamics; Sweden, **2015**; pp 141–158.