Research Article

Estimation and Validation of Land Surface Temperature by using Remote Sensing & GIS for Chittoor District, Andhra Pradesh

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Abstract: Land Surface Temperature (LST) quantification is needed in various applications like temporal analysis, identification of global warming, land use or land cover, water management, soil moisture estimation and natural disasters. The objective of this study is estimation as well as validation of temperature data at 14 Automatic Weather Stations (AWS) in Chittoor District of Andhra Pradesh with LST extracted by using remote sensing as well as Geographic Information System (GIS). Satellite data considered for estimation purpose is LANDSAT 8. Sensor data used for assessment of LST are OLI (Operational Land Imager) and TIR (Thermal Infrared). Thermal band contains spectral bands of 10 and 11 were considered for evaluating LST independently by using algorithm called Mono Window Algorithm (MWA). Land Surface Emissivity (LSE) is the vital parameter for calculating LST. The LSE estimation requires NDVI (Normalized Difference Vegetation Index) which is computed by using Band 4 (visible Red band) and band 5 (Near-Infra Red band) spectral radiance bands. Thermal band images having wavelength 11.2 µm and 12.5 µm of 30th May, 2015 and 21st October, 2015 were processed for the analysis of LST. Later on validation of estimated LST through in-suite temperature data obtained from 14 AWS stations in Chittoor district was carried out. The end results showed that, the LST retrieved by using proposed method achieved 5 per cent greater correlation coefficient (r) compared to LST retrieved by using existing method which is based on band 10.

Keywords: Mono Window Algorithm (MWA), OLI and TIR, Normalized Difference Vegetation Index (NDVI), Land Surface Emissivity (LSE), Land Surface Temperature (LST).

1. Introduction

Surface Temperature of the land could be obtained by using remote sensing from on board sensor in satellite. Extracted temperature is required for many applications like atmospheric models for the calculation of functional heat flux by assessing the change between the land surface temperature and the air temperature near the surface. It's assessment done by using brightness temperature of the Top-of-Atmosphere. Its evaluation additionally depends on aldedo, vegetation cover and soil moisture. (Source: https://land.copernicus.eu/global/products/lst). Satellites with on board sensors of thermal infrared (TIR) instruments are the mainly available operational systems for collecting the LST data that has been used usually in agriculture drought assessment (M.S. Malik et al., 2018), land-atmosphere exchange simulation model, radiation budget estimation and evapo-transpiration etc..

During summer season farmers utilize land surface temperature specifying maps for evaluating water necessities for their crops when they are more prone to high temperature conditions. On the other hand, these maps assist citrus farmers in determining where and when orange orchards have been open to the elements to damaging chill in the winter season. Like this number of real-time applications make use of surface temperature parameter for different atmospheric models. (Source: https://earthobservatory.nasa.gov/).

The observation of diurnal characteristics of land surface temperature provides the opportunity for exploration of the climate change, agricultural drought and estimation of crop yield (Ying Sun et al., 2020; Limin Yang, 2000). A number of LST assessment algorithms had been developed for LANDSAT 7 or 8 satellite data using thermal band data (F. Sattari et al., 2014). Mono-window algorithm is one of the extensively used methods for surface temperature estimation (Fei Wang et al., 2015; Jinqu Zhang et al., 2006). It is used for LST evaluation from single TIR band data of LANDSAT 7 or 8 satellite images using GIS. Other parameters necessary for LST assessment are atmospheric transmittance, ground emissivity and average effective atmospheric temperature.

Land Surface Temperature is used for quantitative analysis of different land use or land cover categories by using Thermal Infra-Red (TIR) sensor of LANDSAT 8. Some of the thermal infrared sensors used for the study of LST with 1km resolution are NOAA (National Oceanic and Atmospheric Administration) Satellite – AVHRR sensor (Advanced Very High Resolution Radiometer), Terra and Aqua Satellites – MODIS (Moderate Resolution Imaging Spectroradiometer). Some of other sensors having high resolution are Terra Satellite - Advanced Space borne Thermal Emission and Reflection Radiometer (ASTER) with resolution of 90 m and LANDSAT 7 satellite – Enhanced Thematic Mapper (ETM+) and LANDSAT 8 Satellite – Thermal Infra-Red (TIR) sensors with 100 m resolution. The estimation of LST is useful for various applications like, Land use /

Land cover change detection, (M. Hemalatha et al., 2018) vegetation, soil moisture, change detection and global warming etc. studies. (M.S. Malik et al., 2018; A.Rajani et al., 2020)

The NDVI (Normalized Difference Vegetation Index) characterizes a number of vegetative properties of land. The LANDSAT 8 having sensor OLI captures images in 9 spectral bands, in that Visible Red band (Band4) and Near-Infrared band (Band5) used for NDVI estimation. NDVI index varies between -1.0 and +1.0. NDVI is used for land use or land cover classification. Based on the index values of NDVI Land cover classification was done into dense forest, water bodies, Baren land, built-up area and spare vegetation (A.Rajani et al., 2020).

The present study focus is on feasibility of finding LST by using band11 data from TIR sensor of LANDSAT 8. The algorithm used for the proposed method is Mono Window Algorithm. After finding LST using band11 then it is compared with the AWS data i.e. error is estimated. And also considering data obtained by D.Jeevalakshmi et al., 2017 for finding LST using band10 and then its difference with AWS data. Finally correlation coefficient is generated using statistical tool for the proposed method and the method used by D.Jeevalakshmi et al., 2017. Land surface emissivity is one of essential parameter for the estimation of LST. LSE estimation requires proportion of vegetation. NDVI is used to estimate proportion of vegetation. The GIS software used for processing LANDSAT 8 satellite image is ArcGIS 10.3.

2. Study Area

Study area selected is Chittoor district which is extreme south of the Andhra Pradesh state. It lies between 12.616667 - 14.133333 N latitudes and 78.05 - 79.916667 E longitudes to the south of Andhra Pradesh state. The temperature is lower in Punganur, Madanapalle and Horsley Hills i.e western portions of the district when it is related to the eastern portions of the district. As western portions are at higher altitude compared to eastern portions so that lower temperatures are observed. In summer temperature ranges between 36.0° to 38.0 °C in the western portions and touches 46.0 °C in the eastern portions of the chittoor district. The winter temperatures of the eastern portion is around 16.0°C to 18.0 °C whereas western portions temperatures are at low ranging around 12.0 °C to 14.0 °C (source: https://en.wikipedia.org/wiki/Chittoor,_Andhra_Pradesh). Figure 1 illustrates Geographical site of the area of interest chosen for this particular study.

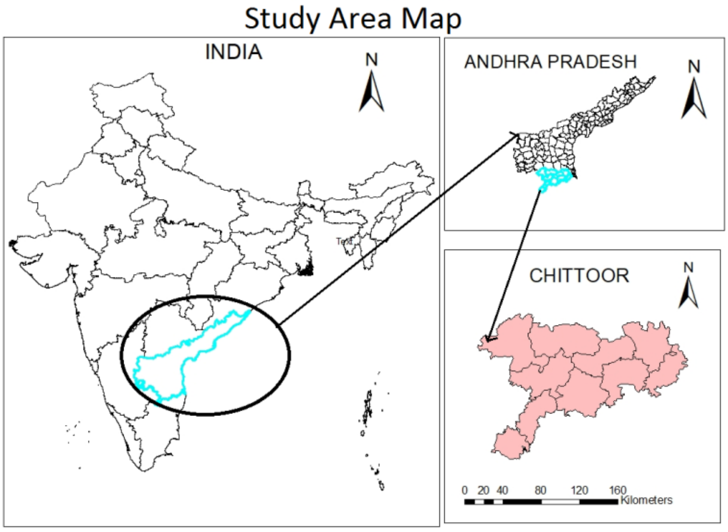

Figure 1. Geographical mapping of Study Area – Chittoor District, Andhra Pradesh, India

2.1 Image Selection

The LANDSAT 8 is an earth observation satellite of America which carries sensors like the Thermal Infrared Sensor (TIRS) and Operational Land Imager (OLI) instruments on board for measuring metrological parameters. (Source: http://landsat.usgs.gov/Landsat8_ Using_Product.php, 2013) Multispectral and multiple band images of LANDSAT 8 were downloaded from USGS earth explorer website (Source: https://earthexplorer.usgs.gov/). The LANDSAT 8 crosses and captures every point on the Earth for every 16 days once. The sensors like OLI and TIRS provide information in 11 spectral bands. Image is selected based on path and row information. Hence, here 143/51 chosen which is the path/row of the study area is selected for the LST estimation purpose and this swath covers maximum area of Chittoor District. Image for the date 30th May, 2015 and 21st October, 2015 (morning 5:00 am, LANDSAT 8 Collection -1 and Level -1 of OLI/TIR) were chosen for Land Surface Temperature estimation. The images were selected with minimum cloud cover so that most of the image area is suitable for study purpose. The projection of satellite image on to the Universal Traverse Mercator (UTM) with

UTM_ZONE = 44 selected here for image projection in ArcGIS software. Satellite image and spectral band information are mentioned in the Table 1.

Table 1. Spatial information about study area

Data Source	Sensor	Date	Spatial Resolution	Bands Considered	Path / Row
LANDSAT 8	OLI/TIRS	30-05-2015 & 21-10-2015	30 meters 100 meters	4 & 5 10 & 11	143/51

3. Methodology

The proposed work is to estimate LST of study area, i.e. Chittoor district by using band 10 and band 11 independently using Mono Window Algorithm. Mono Window algorithm comprises 6 steps process in the estimation of the LST of the study area. These steps are specifically used for processing the LANDSAT 8 band data only. LST assessment requires brightness temperature, Land surface emissivity and NDVI values.

Mono window algorithm uses both the bands, i.e. 10 and 11 of LANDSAT 8 Thermal Infra-Red sensor (M Wang et al., 2019; Ugur Avdan et al., 2016) independently. Land surface temperature is estimated by using band 10 and 11 separately for comparison of which one performs better. After retrieving land surface temperature from multiple spectral bands and multiple sensors, it is used to validate with in-suite data obtained from AWS stations. The LST estimated by using remote sensing and GIS is compared with in-suite AWS stations temperature data and difference of two temperatures is calculated. Eventually, the correlation coefficient of LST and AWS data is computed and analyzed. Flowchart for LST retrieval process and validation method is specified in figure 2.

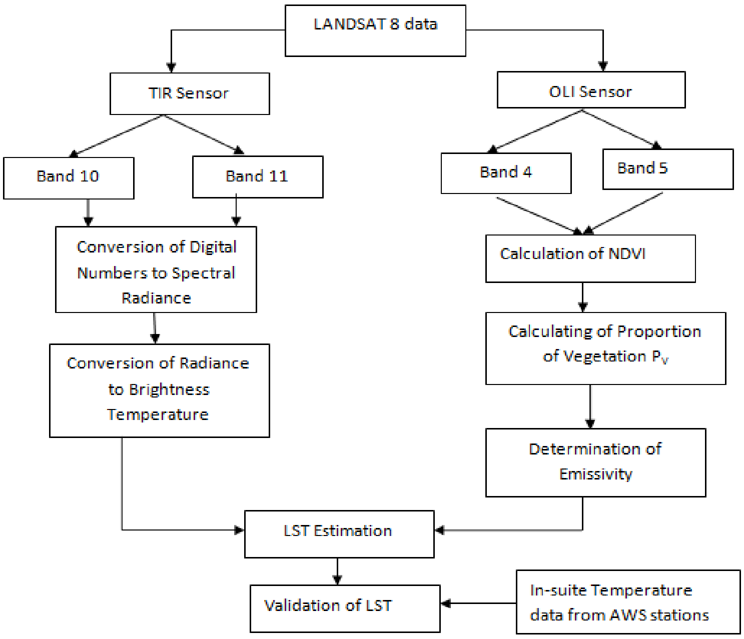

Figure 2: Flow chart for LST estimation and validation process

GIS software used for the assessment of LST from LANDSAT 8 data was ArcGIS10.3. The processing steps involved in Mono-Window Algorithm for estimating LST are as follow.

Step 1

Translation of satellite image Digital Number (DN) into spectral radiance called Top of Atmosphere (TOA) is done by applying the equation number (1) and the band specific parameters are presented in the Table 2. These parameters obtained from metadata file.

$$L_{\lambda} = M_L * Q_{cal} + A_L - O_i \qquad (1)$$

Where,

L_{λ} - Spectral radiance of TOA (mW /sr mm^2)

M_L - Multiplicative rescaling value

A_L - Additive rescaling factor of specific band

Q_{cal} – Digital Number (i.e. Quantized and calibrated pixel values)

O_i - Adjustment factor

Table 2. Band Specific Parameters

Parameter	Band 10	Band 11
M_L	3.342 x10^{-4}	3.342 x10^{-4}
A_L	1x10^{-1}	1x10^{-1}
O_i	0.29	0.51

Step 2

Conversion of Top of Atmosphere (TOA) radiance into brightness temperature (B_T) by using L_λ and band specific thermal conversion constants K_1 and K_2 specified in metadata file of satellite image. The resultant temperature is obtained in Kelvin. It is converted into Celsius by adding the absolute zero (-273.15^0 C). Brightness temperature in Celsius is estimated by the equation (2). The thermal conversion constants are shown in the Table 3.

$$B_T = \frac{K_2}{ln\left[\left(\frac{K_1}{L_\lambda}\right)+1\right]} - 273.15 \longrightarrow (2)$$

Where

B_T - Brightness Temperature in ^{0}Celsius

L_λ - Top of Atmospheric spectral radiance (Band 10 or Band 11)

K_1 and K_2 – Thermal Sensor constants used for conversion (Source: metadata file)

Table 3. Thermal conversion constants

Parameter	Band 10	Band11
K_1	77489 x10^{-2}	48089 x10^{-2}
K_2	132108 x10^{-2}	120114 x10^{-2}

Step 3

The OLI (Operational Land Imager) sensor spectral images of bands 4 and 5 used for calculating NDVI (Normalized Difference Vegetation Index). The NDVI values vary between -1.0 to +1.0. That depends on the various objects on the land surface which is going to be captured by the sensor. NDVI of each pixel is estimated by using Red band (0.64 µm), i.e. band 4 and Near Infrared band (0.85 µm), i.e. band 5 of LANDSAT 8 by using the equation no. (3)

$$NDVI = \frac{(Band5) - (Band4)}{(Band5) + (Band4)} \longrightarrow (3)$$

Calculation of NDVI is necessary for estimation of vegetation proportion (P_v) and land surface emissivity (LSE i.e. ε) parameter which are needed for estimating the Land Surface Temperature.

Step 4

Vegetation proportion (P_v) is calculated by using equation number 4, where NDVI is obtained from step 3.

$$P_V = \left(\frac{NDVI - NDVI_{min}}{NDVI_{max} - NDVI_{min}}\right)^2 \longrightarrow (4)$$

After the estimation of NDVI values of study area, then consider from that NDVI image lowest and highest values of the NDVI image.

Step 5

Land Surface Emissivity (ε) anticipated through the use of the NDVI threshold method. LSE is essential parameter for calculating the LST, because it is a proportionality thing that is used to scale blackbody radiance (Planck's law) so that emitted radiance can be predicted. Moreover, it's capability of passing on thermal energy throughout the surface and into the atmosphere (Jeevalakshmi D et al., 2017; M S Malik et al., 2018). Therefore the land surface emissivity (ε) is computed by using the equation no.(5)

$$\varepsilon = \varepsilon_s (1 - P_v) + \varepsilon_v P_v + d\varepsilon \longrightarrow (5)$$

Where,

ε_v denotes Emissivity parameter of Vegetation

ε_s denotes Emissivity parameter of soil

P_v – Vegetation proportion (Jeevalakshmi D et al.,2017).

Final Emissivity (ε) for the land surface area of LANDSAT 8 image is computed by the equation no. (6)

$$\varepsilon = 0.986 + 0.004 * P_v \longrightarrow (6)$$

Where,
0.004 - Standard deviation of soil bands,
0.989 - Average Emissivity (i.e average of soil and vegetation emissivity factors)

Step 6

The ultimate step of estimating the LST is by using the equation (7)

$$LST = \frac{B_T}{\left\{1+\left[\left(\frac{\lambda B_T}{\rho}\right) ln ln\, (\square_\square)\right]\right\}} \ ^\circ C \qquad \longrightarrow (7)$$

Where,
λ = 10.8 μm i.e. Emitted radiance wavelength
ε_λ - land surface emissivity and

$$\rho = h\frac{c}{\sigma} = 14388\ \mu m\ K \qquad \longrightarrow (8)$$

Where,
c – Light Velocity = 3×10^{8} m/s
σ – Boltzmann's Constant = 138×10^{-25} J/K and constant
h - Planck's Constant = 662.6×10^{-36} Js.
Land surface temperature has been estimated for the study area considering two seasons 30th May, 2015 and 21st October, 2015. After estimation validation is performed by comparing the LST of satellite image with in-suite data from AWS stations. (Jeevalakshmi D et al., 2017).

4. Results and Discussions

Land surface temperature obtained using remote sensing and GIS technique. Each pixel in the image represents the surface temperature of each object that may be group of numerous land cover types. By using above mentioned processing steps especially for LANDSAT 8 data LST maps are generated independently for both the thermal bands 10 & 11. Retrieved Land Surface Temperature of band 10 and band 11 maps for the dates 30-05-2015 and 21-10-2015 are shown in the figures 3, 4, 5 and 6 respectively. Figures 3, 4, 5 and 6 illustrate the map of LST related to study area where 14 AWS stations are pointed using bi-linear interpolation method. The NDVI maps of the study area for the days 30-05-2015 and 21-10-2015 are shown in the figures 7 and 8. Spatial spreading of surface temperature within the study area is shown in LST maps. From these maps it is observed that different land cover types are having various temperature values due to variations in physical characteristics of the land covered by the different objects.

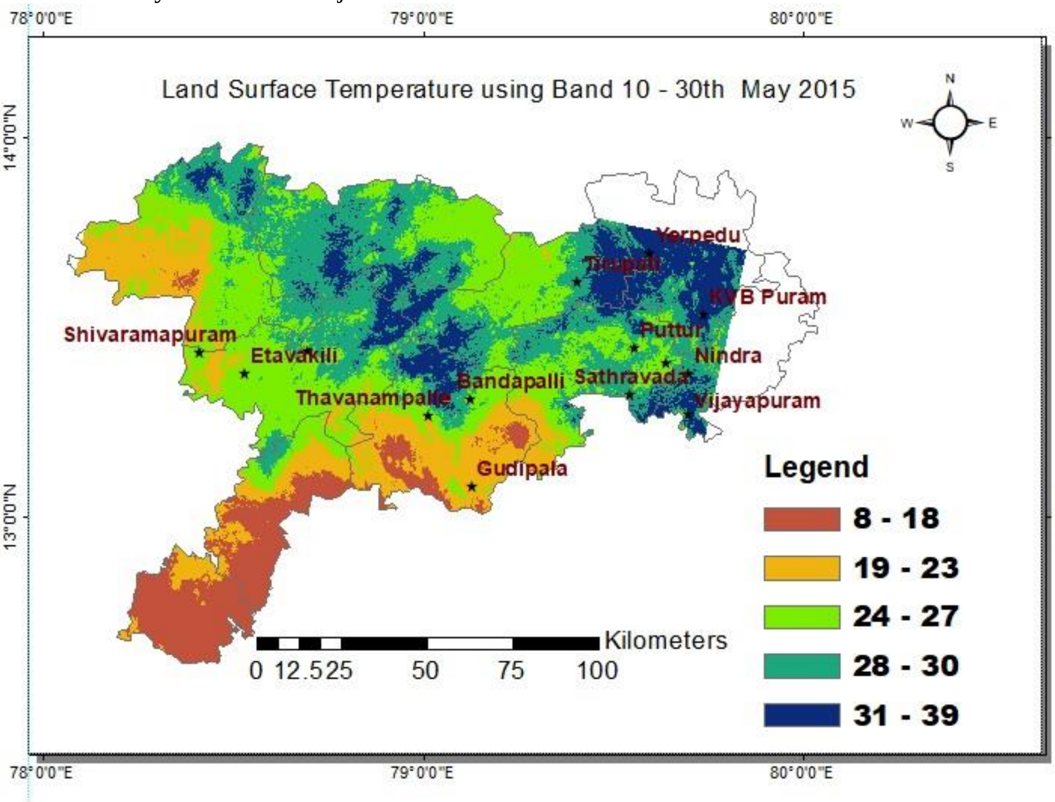

Figure 3: LST map using band 10 for 30-May-2015

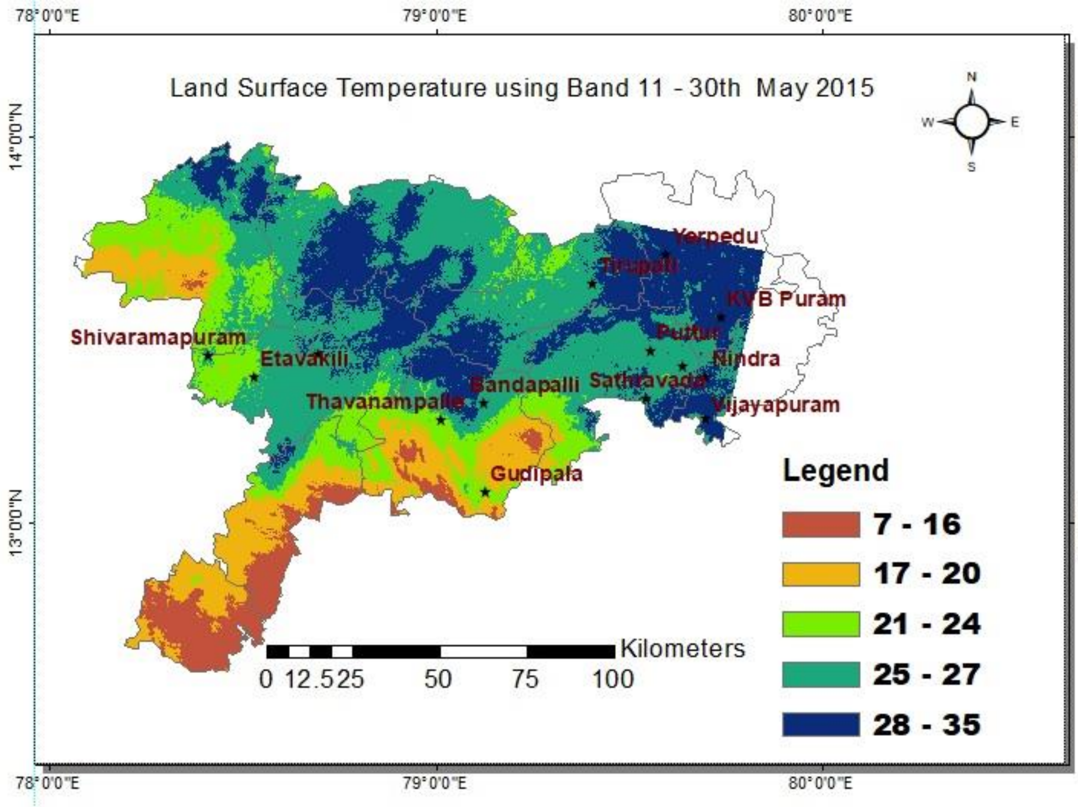

Figure 4: LST map using band 11 for 30-May-2015

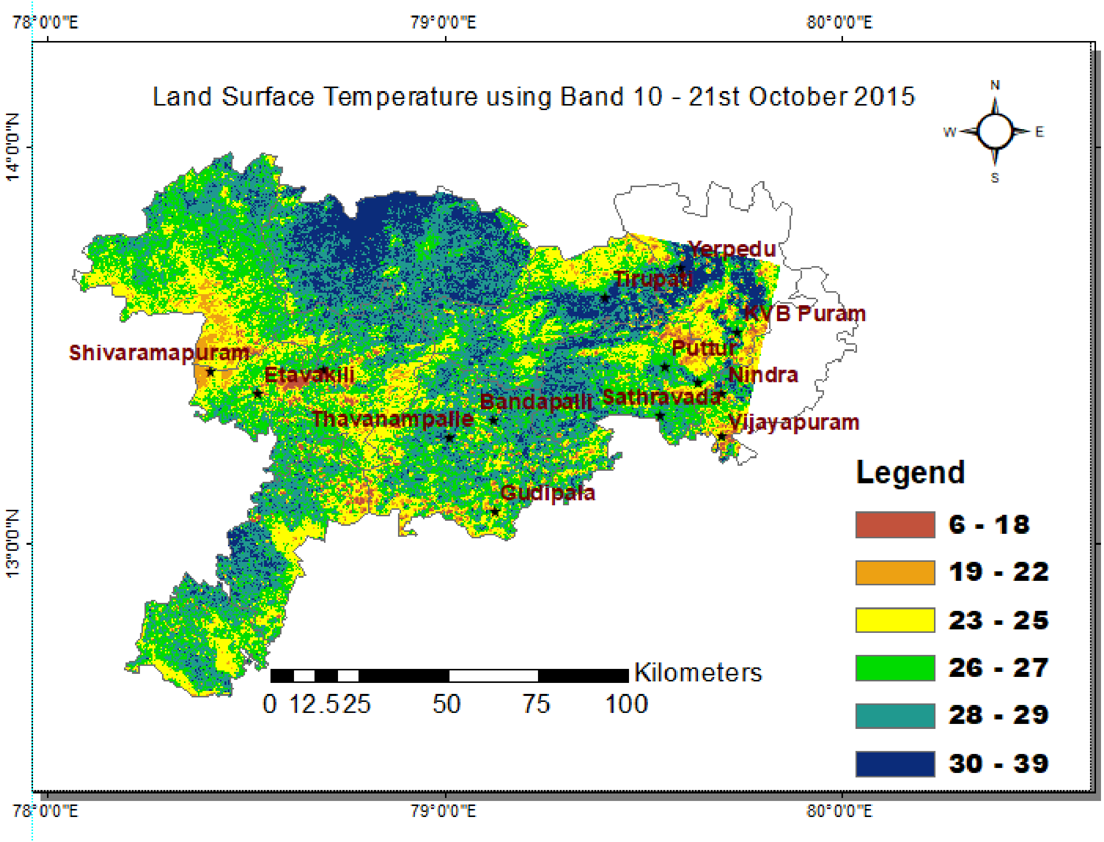

Figure 5: LST map using band 10 for 21-October-2015

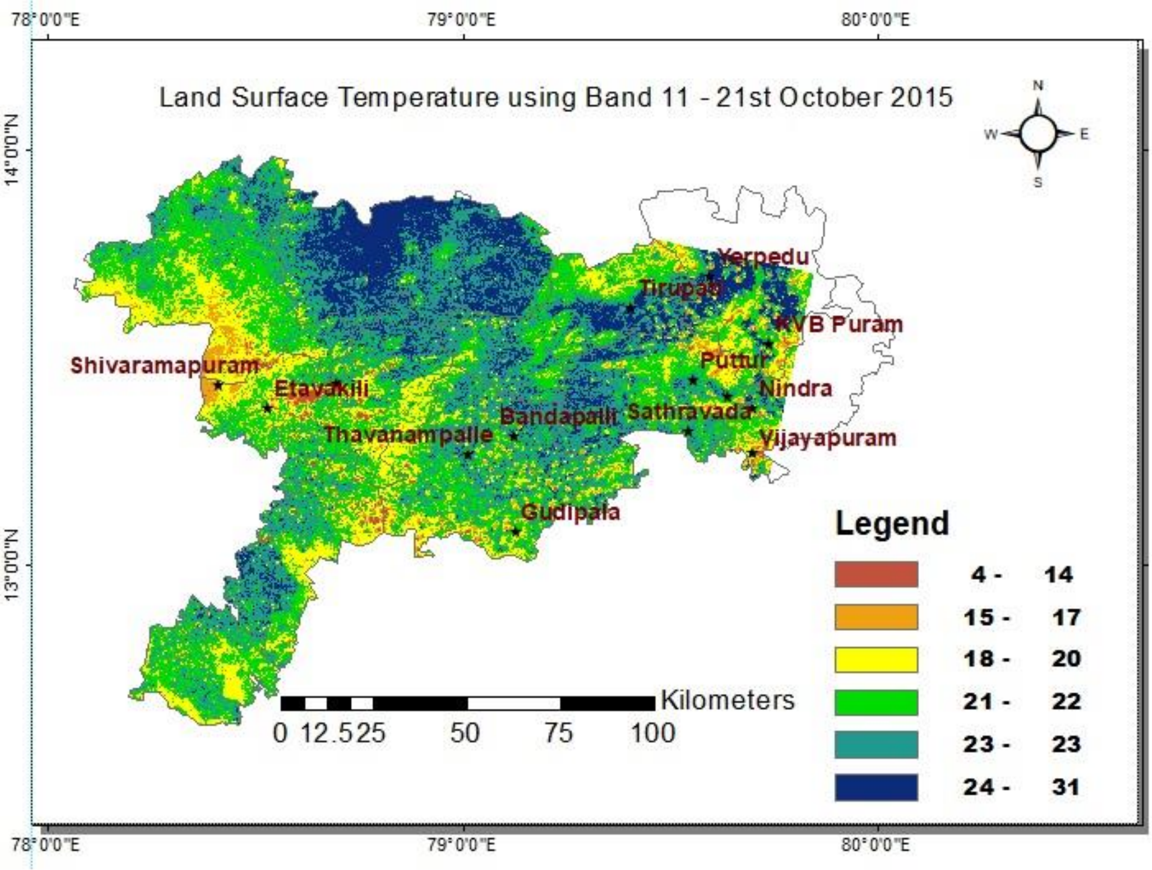

Figure 6: LST map using band 11 for 21-10-2015

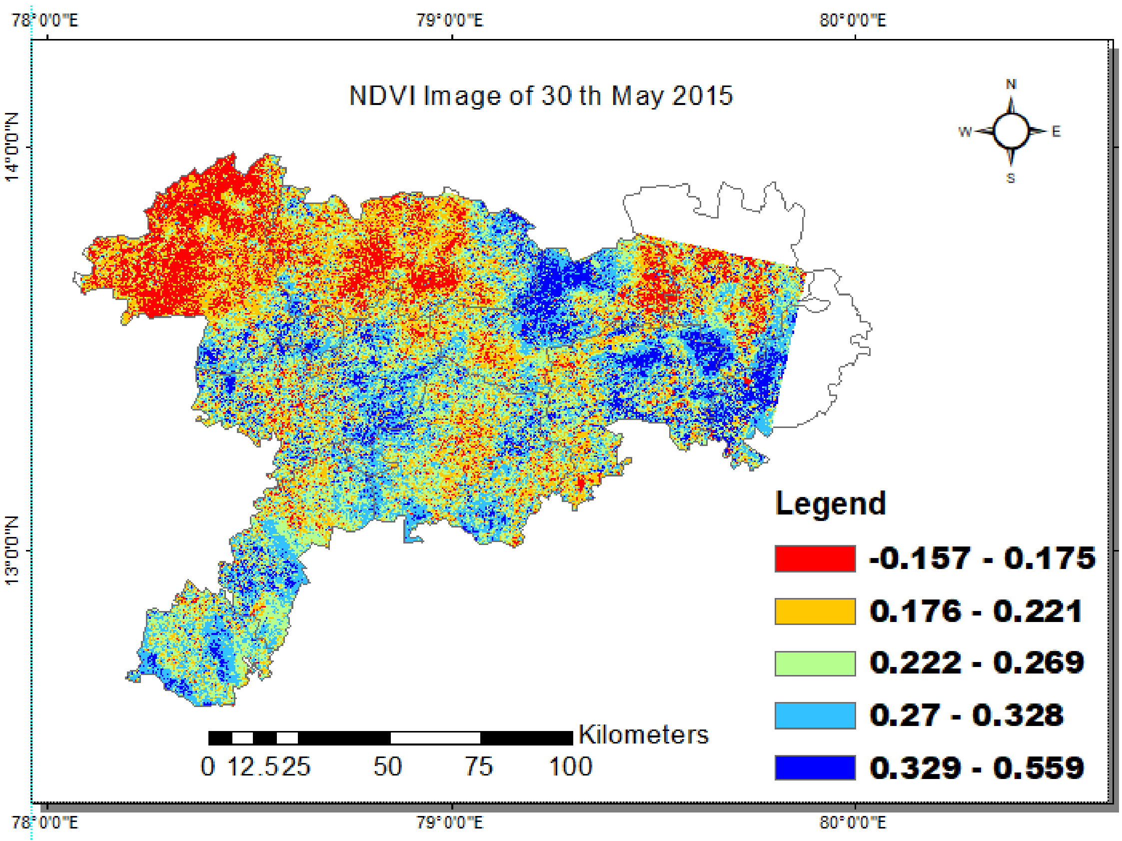

Figure 7: NDVI image of the study area for 30-May-2015

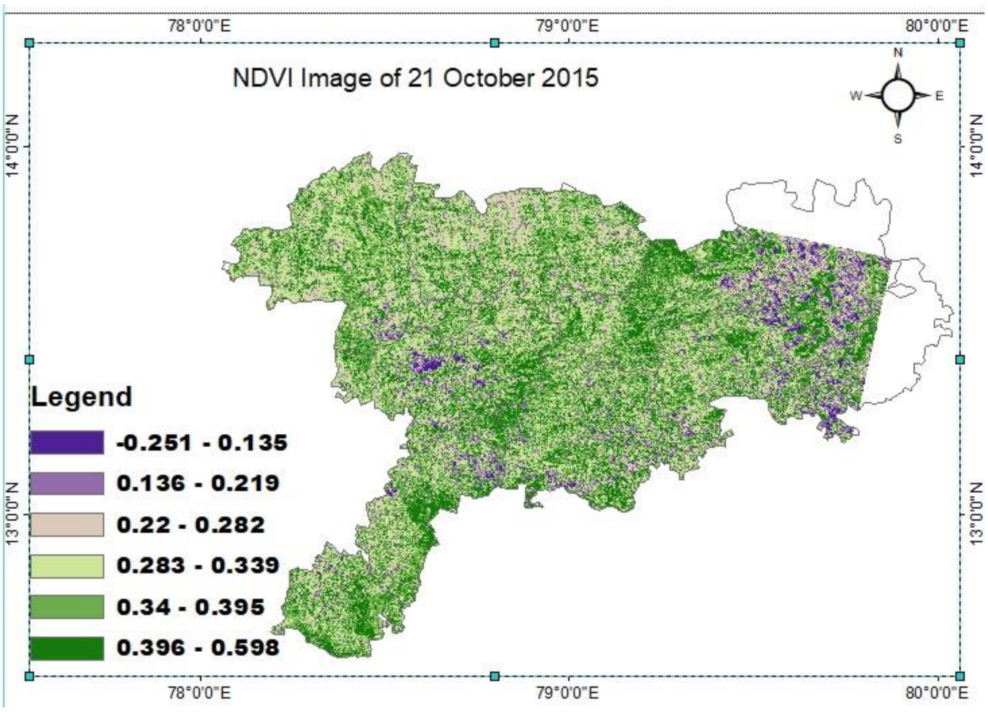

Figure 8: NDVI image of the study area for 21-October-2015

The objective of this work is that, estimation and validation of LST from the LANDSAT 8 image with in-suite data obtained from 14 Automatic Weather Station (AWS) centers at Chittoor District, Andhra Pradesh. Most of the authors suggested the estimation of the LST by using thermal image of band 10 by using Mono Window algorithm (Jeevalakshmi D et al., 2017; Ugur Avdan et al., 2016;). Otherwise, the LST estimation by using both thermal band images of band 10 and 11 by using Split window algorithm (A. Sabrino et al., 2008; M. Wang et al., 2019). This work considers band 11 instead of band 10 for LST calculation. It compares the resultant LST values of both band 10 and band 11 with in-suite AWS data. Regression analysis is done between band10 and AWS data and also band 11 and AWS data. Statistical analysis is done by calculating correlation coefficient between retrieved LST from band 10 and in-suite AWS data and also LST retrieved by using band 11 & in-suite AWS data. With reference to D.Jeevalakshmi et al., 2017 comparison is performed through LST of band 10 and the proposed method. Table 4 and 5 show the LST retrieved by using Band 10 and Band 11 by using Mono Window Algorithm and AWS data for 30-05-2015 and 21-10-2015. Table 4 and 5 also show various land cover types along with difference of temperatures between in-suite measurements from AWS stations and LST of band 10 and band 11, i.e. error by using Mono Window Algorithm estimation method.

Table 4. Comparison of LST Retrieved by using Band 10 and Proposed method with AWS data for 30th May, 2015

Sl. No.	Location	Latitude	Longitude	Land Cover Types	NDVI	AWS Data at 5A.M. (^{0}C)	LST Retrieved using Band 10 (^{0}C)	Error using Band 10	(Proposed Method) LST Retrieved using Band 11 (^{0}C)	Error using Band 11
1	Puttur	13.443777	79.556068	Built up	0.119	28.2	25.58	2.62	25.83	2.37
2	Chowdepalle	13.434461	78.692558	Bare land	0.042	24.41	26.83	-2.42	26.44	-2.03
3	Gudipala	13.078956	79.125069	Dense Vegetation	0.335	23.52	21.64	1.88	21.58	1.94
4	Aranyakandriga	13.402667	79.63726	Dense Vegetation	0.305	27.18	25.67	1.51	25.4	1.78
5	Nindra	13.376643	79.699702	Vegetation	0.261	28.53	30.68	-2.15	28.86	-0.33

6	Thavanampalle	13.262898	79.012993	Vegetation	0.046	22.95	23.54	-0.59	22.28	0.67
7	Vijayapuram	13.267402	79.698624	Vegetation	0.346	25.46	27.82	-2.36	26.87	-1.41
8	Yerpedu	13.693141	79.593695	Built up	-0.045	29.46	30.96	-1.5	29.46	0
9	KVB Puram	13.53205	79.73996	Vegetation	0.044	31.23	31.94	-0.71	31.2	0.03
10	Shivaramapuram	13.430556	78.409444	Vegetation	0.146	24.06	25.15	-1.09	24.06	0
11	Tirupati	13.6175	79.403333	Built up	0.153	30.07	27.62	2.45	26.96	3.11
12	Etavakili	13.374444	78.526667	Built up	0.015	21.15	23.74	-2.59	22.61	-1.46
13	Bandapalli	13.307083	79.121117	Bare land	0.105	25.98	26.17	-0.19	26.45	-0.47
14	Sathravada	13.32085	79.542483	Vegetation	0.163	25.27	26.82	-1.55	26.09	-0.82

The correlation coefficient of AWS temperature data with LST retrieved by using band 10 is r= **0.801613419.** The **c**orrelation coefficient of AWS temperature data with LST retrieved by using band 11(Proposed method) is r= **0.855623779.** From the results analysis, it is observed that LST retrieved by using band 11 is having 0.0487 greater correlation than LST retrieved by using band 10. The correlation coefficient can be estimated by using equation 9

$$r = correl(x, y) = \frac{\Sigma \quad (x-\underline{x})(y-\underline{y})}{\Sigma \quad (x-\underline{x})^2(y-\underline{y})^2} \qquad \textbf{(9)} \longrightarrow$$

From the results, it can be concluded that the land surface temperature retrieved by using band 11 is having more correlation coefficient compared to the LST retrieved by using band10. Figure 9 shows plotting of retrieved LST and AWS data for the study area by using band 10 and band 11 independent results graph for the day 30th May 2015. From the plot it can be witnessed that the retrieved LST using band11 is having less deviation compared to AWS data from the study area for the chosen 14 weather stations.

Similar analysis is done for the LANDSAT 8 image for the day 21st October, 2015 of the study area having 14 AWS stations.

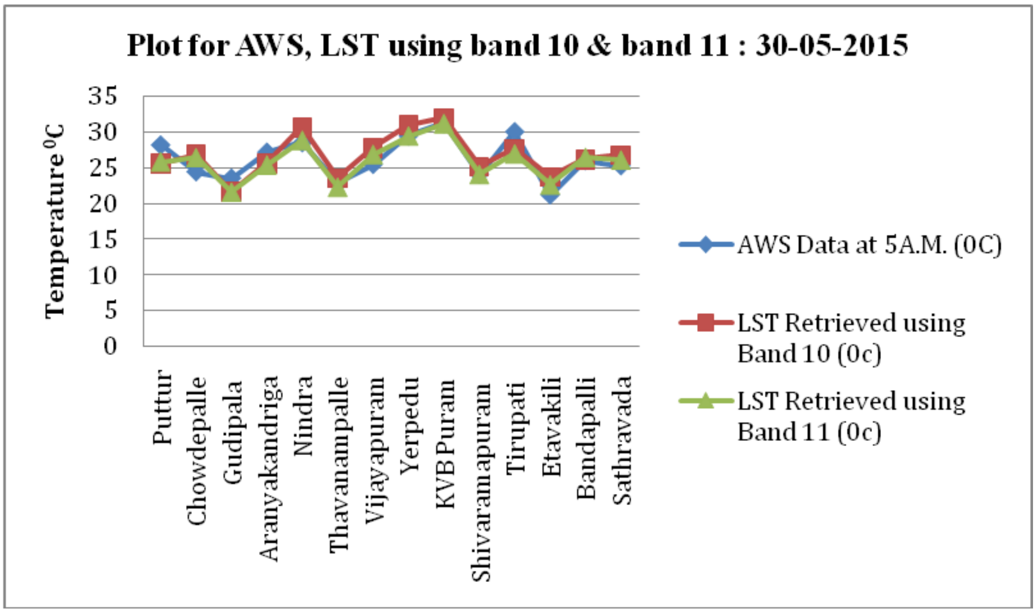

Figure 9. Plot showing AWS data & LST retrieved using Band 10 & Band 11 for 30-05-2015

Table 5. Comparison of LST Retrieved by using Band 10 and proposed method with AWS data for 21st October, 2015

Sl. No.	Location	Latitude	Longitude	Land Cover Types	NDVI	AWS Data at 5A.M. (^{0}C)	LST Retrieved using Band 10 (^{0}C)	Error using Band 10	(Proposed Method) LST Retrieved using Band 11 (^{0}C)	Error using Band 11
1	Puttur	13.44378	79.556068	Built up	0.108	25.53	25.4	0.13	25.12	0.41
2	Chowdepalle	13.43446	78.692558	Bare land	0.003	23.96	24.52	-0.56	23.74	0.22
3	Gudipala	13.07896	79.125069	Dense Vegetation	0.529	23.01	24.5	-1.49	23.52	-0.51
4	Aranyakandriga	13.40267	79.63726	Dense Vegetation	0.574	24.63	25.83	-1.20	23.76	0.87
5	Nindra	13.37664	79.699702	Vegetation	0.457	24.25	25.24	-0.99	23.92	0.33
6	Thavanampalle	13.2629	79.012993	Vegetation	0.215	22.06	24.90	-2.84	22.30	-0.24
7	Vijayapuram	13.2674	79.698624	Vegetation	0.429	23.60	23.41	0.19	22.91	0.69
8	Yerpedu	13.69314	79.593695	Built up	0.050	24.78	27.66	-2.88	23.54	1.24
9	KVB Puram	13.53205	79.73996	Vegetation	0.242	24.89	25.65	-0.76	25.10	-0.21
10	Shivaramapuram	13.43056	78.409444	Vegetation	0.377	21.18	22.49	-1.31	20.15	1.03
11	Tirupati	13.6175	79.403333	Built up	0.191	27.04	28.53	-1.49	24.69	2.35
12	Etavakili	13.37444	78.526667	Built up	0.093	21.55	24.01	-2.46	21.08	0.47
13	Bandapalli	13.30708	79.121117	Bare land	0.100	22.19	21.60	0.59	23.25	-1.06
14	Sathravada	13.32085	79.542483	Vegetation	0.215	25.01	26.03	-1.02	24.46	0.55

Correlation coefficient of AWS temperature data with LST retrieved by using band 10 for 21st October, 2015 is r= **0.81830048.** Correlation coefficient of AWS temperature data with LST retrieved by using band 11 for 21st October, 2015 **is r= 0.86700979.** From the analysis of results it is observed that the LST retrieved by using proposed method is having 0.05401 greater correlations than LST retrieved by using band 10. Figure 10 shows a plotting of AWS data and estimated LST for the chosen area using the independent results graph with band10 and band11 for the day 21st October 2015.

From the plot, it can be seen that the LST recovered using band11 has less deviation compared to AWS data for the selected 14 weather stations selected in the region studying

Figure 10. Plot showing AWS data & LST retrieved using Band 10 & Band 11 for 21-10-2015

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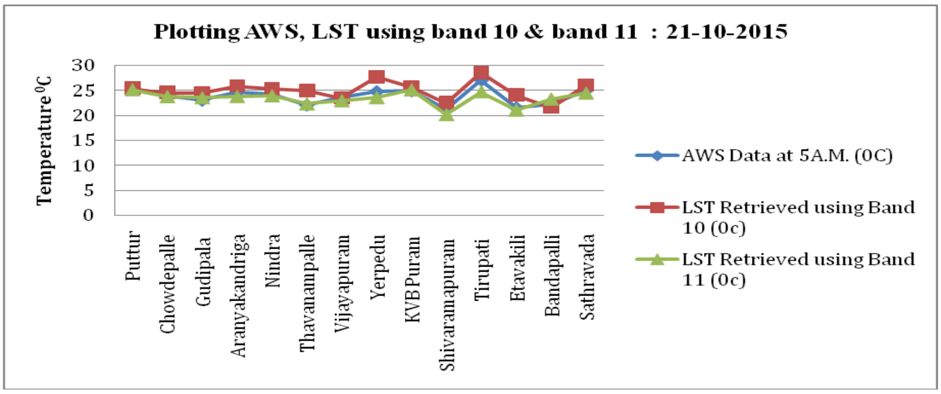

5. CONCLUSIONS

This research work considered 14 AWS stations as validation points from study area for the validation purpose. The LST was retrieved by using Mono Window Algorithm. Here both the thermal bands of TIR sensor of LANDSAT 8 are used. Most of the research work utilized band 10 for the extraction of LST. With the use of band 11 for LST extraction, more correlation coefficient is observed. The estimated LST using remote sensing and GIS were validated by in-suite measures taken from same geographical locations. And also both observations consider same date and time. Here for the proposed work estimation satellite data considered two dates 30-05-2015 and 21-10-2015. Time was local standard time 5.00 A.M. More deviation has been observed when compared to estimated LST using band 10 with AWS data. Whereas less deviation observed while comparing estimated LST using proposed method by using band 11 with AWS data. Therefore, retrieved LST based on band 11 measurements were having ~5 per cent more correlation coefficient compared to band10 LST of the in-suite AWS stations temperature of the study area.

Conflict of interest:

There is no conflict of interest.

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