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Land surface temperature estimation of a distributary of Mahanadi canal command using LANDSAT-7 and LANDSAT-8 satellite data using Sebal algorithm for rice and wheat crops

Manju Dhruw and VK Pandey

Abstract
Land Surface Temperature (LST) is one of such parameter on which the growth of vegetation and soil biological micro and micro living depend. Variation in LST may directly affect crop productivity and soil fertility. LST is an applied tool for many climatic models and an important element in different areas like heat balance studies, land cover, land use and climate change. Due to advancement in technology, remote sensing imagery provides a suitable platform to estimate LST accurately. In the present study, LST has been estimated using LANDSAT 7 and 8 imagery from SEBAL algorithm for 15 years of Rice & Wheat Crops. The optical and thermal bands of LANDSAT 7 and 8 have been to estimate LST of 2A distributary of Mahanadi canal Command which is situated in Dhamtari district of Chhattisgarh state of India. This present study can provide a reference for land use planning, restoration of ecological environment and sustainable development in 2A Distributary. Land Surface Temperature was found to be maximum 43.495 ^{0}C.in 2009 and minimum 28.542 ^{0}C in 2008 for Rice Crop and for Wheat Crop was found to be maximum 34.793 ^{0}C in 2012 and minimum 23.806 ^{0}C in 2021.

Keywords: Remote sensing, GIS, SEBAL algorithm, thermal band, optical band, land surface temperature (lst), Landsat 7 and 8.

Introduction
Land Surface Temperature (LST) can be defined as the temperature felt when the land surface is touched with the hands or it is the skin temperature of the ground. As one of the most important aspects of the land surface, LST has been a main topic for developing methodologies to be measured from space. LST is an important factor in many areas of studies, such as global climate change, hydrological and agricultural processes, and urban land use/land cover. Calculating LST from remote sensed images is needed since it is an important factor controlling more physical, chemical, and biological processes of the Earth. Land surface temperature can provide important information about the physical surface properties and climate which plays a role in many environmental processes. Many studies have estimated the relative warmth of cities by measuring the air temperature, using land based observation stations. Some studies used measurements of temperature using temperature sensors mounted on car, along various routes. This method can be both expensive and time consuming and lead to problems in spatial interpolation. Remote sensing might be a better alternative to the aforesaid methods. The advantages of using remotely sensed data are the availability of high resolution, consistent and repetitive coverage and capability of measurements of earth's surface conditions. Throughout the world, Urbanization and other such activities have increased alarmingly the greenhouse gases and redesigned the landscape which has hostile climatic effects beyond all scales. Filed inspections can provide a very accurate data for the classification of Land Use Land Cover (LULC), but they are expensive, which point remote sensing preferred and an evident alternative. Medium spatial resolution data, such as that from the LANDSAT and SPOT are suitable for land cover or vegetation mapping at regional local scale. Urban Heat Island (UHI) is based typically on LST owing to non-homogeneity of land surface cover and other factors of atmosphere. LST is the key factor for the calculation of highest and lowest temperature of a specific place. The key objective of the present study is to find out the brightness temperature by using band 6 for LANDSAT 7 AND band10 for LANDSAT 8 TIR, to estimate the LST of 2A Distributary by using SEBAL Algorithm.

Description of Study Area
The present study was carried out in Kurud block of Mahanadi Command area in Chhattisgarh State of Northern part of Dhamtari district. The area lies between $20^{0}42'04''$ and $21^{0}{'}29''$ N latitudes and $81^{0}47'50''$ and $81^{0}85'30''$ E longitudes. The geographical area of the distributary 2A was 200.05 KM^2 with Cultivable Command Area (C.C.A) of 12461.58 ha. Mahanadi is the principal river of the Dhamtari district along with its tributaries and Kharun on western boundary of block respectively. The area is served by a good road network from the capital city Raipur. The major crop of the area is paddy in kharif season and in Rabi season mostly summer paddy and wheat, chickpea, pulses (mainly gram and millets) and oil seeds are grown. 2A Distributary shown in Fig.1.

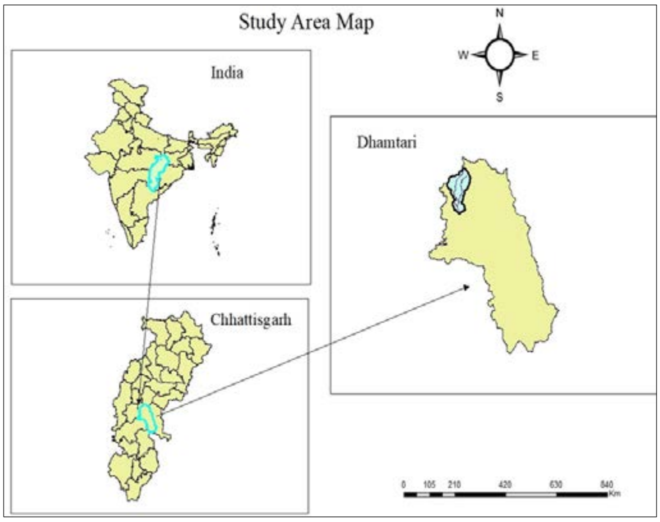

Fig 1: Location map of the study area

Materials and Methods
Data Used
Landsat- 7 and 8 is one of the National Aeronautics and Space Administration (NASA) Landsat series. The Landsat-7 and 8 data is accessible in United States Geological Survey (USGS). The website Earth Explorer is free of cost. The Landsat Enhanced Thematic Mapper Plus (ETM+) sensor onboard the Landsat 7-8 satellite is collecting images of the Earth on a 16-day repeat cycle. In the current study, to estimate brightness temperature the TIR bands (6, 10) were used. Satellite data for 2A Distributary LANDSAT-7 from 2007-2013 and LANDSAT-8 from 2014- 2021 were used in current study. Landsat 7 and 8 provides metadata of the bands such as thermal constant, rescaling factor value etc., which can be used for Calculation like LST. Bands, Wavelength and Resolution of Landsat 7 and 8 are as given in Table – 1, 2.

Table 1: Band specifications of Landsat7 Enhanced Thematic Mapper Plus (ETM+)

Landsat-7	Wavelength(micrometers)	Resolution(m)
Band1	0.45-0.52	30
Band2	0.52-0.60	30
Band3	0.63-0.69	30
Band4	0.77-0.90	30
Band5	1.55-1.75	30
Band6	10.40-12.50	60(30)
Band7	2.09-2.35	30
Band8	0.52-0.90	15

Landsat 7 Enhanced Thematic Mapper Plus (ETM+) images consist of eight spectral bands with a spatial resolution of 30 meters for Bands 1 to 7. The resolution for Band 8 (panchromatic) is 15 meters.

Table 2: Band specifications of Landsat 8 OLI

Landsat-8	Wavelength (micrometers)	Resolution(m)
Band1-Coastalaerosol	0.43-0.45	30
Band2- Blue	0.45-0.51	30
Band3-Green	0.53-0.59	30
Band4-Red	0.64-0.67	30
Band5-Nearinfrared(NIR)	0.85-0.88	30
Band6-SWIR1	1.57-1.65	30
Band7-SWIR2	2.11-2.29	30
Band8-Panchromatic	0.50-0.68	15
Band9-cirrus	1.36-1.38	30
Band10-ThermalInfrared(TIRS)1	10.60-11.9	100*(30)
Band11-Thermal Infrared(TIRS)2	11.50-12.51	100*(30)

*ETM+ Band 6 is acquired at 60- meter resolution. Products processed after February 25, 2010 are resampled to 30- meter pixels.

Software's used
- Arc GIS Pro 10.3
- ERDAS IMAGINE 2014

Methodology
Calculate Land Surface Temperature (LST)
For Landsat-7
The approach to the proposed work to estimate LST is shown in the Figure 2. This technique can only be used to processLandsat-7 (band 6) is used respectively. Thestepsinvolvedintheproposedworkaredetailedinthefollowingliterature.

Step 1
In Landsat-7 first scan line error is removed in Arc-Gis software of band 6 and band (4-3).

Step 2
1. The satellite data products were geometrically corrected data set. The metadata of the satellite images is taken.
2. The first step of the proposed work is to convert the DN (Digital Number) values of band 6 to at-sensor spectral radiance using the following equation:

$$L\lambda = ((LMAX\lambda - LMIN\lambda)/(QCALMAX - QCAL\ MIN) \times (QCAL - QCAL\ MIN) + LMIN\lambda) \quad .....(1)$$

Where,
Lλ= Spectral Radiance (watts/meter)
QCAL= Quantized calibrated pixel value in DN
LMAXλ= Spectral Radiance scaled to QCAL MAX (watts/meter)
LMINλ= Spectral Radiance scaled to QCAL MIN (watts/meter)
QCALMAX = Maximum Quantized calibrated pixel value (corresponding to LMAXλ) in DN
QCALMIN = Minimum Quantized calibrated pixel value (corresponding to LMINλ) in DN
Step3:
After converting DN values to at-sensor spectral radiance the TIRS band data should be converted to brightness temperature (BT) using the thermal constants given in metadata file and the following equation

$$T = \frac{K2}{\ln\left(\frac{K1}{L\lambda}+1\right)} \quad .....(2)$$

Where K1 and K2 are the thermal constants of TIR band 6which can be identified in the metadata file associated with the satellite image. To have the results in Celsius, it

is necessary to revise by adding absolute zero which is approximately equal to - 273.15.

Table 3

Variable	Description	Value
K1K2	Thermal constants, Band 6	666.09 1282.71
Lmax Lmin	Maximum and Minimum values of Radiance, Band 6	17.040 0
Qcalmax Qcalmin	Maximum and Minimum values of Quantize Calibration Band 6	255 1

Step 4

Convert Degree Kelvin into Degree Celsius

C = K – 273.15 .....(3)

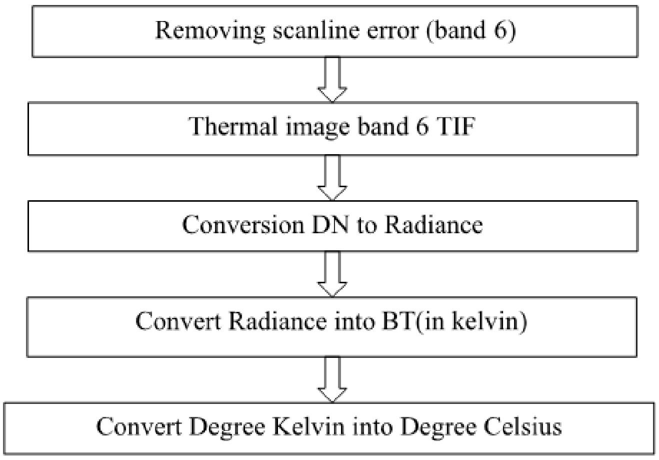

Fig 2: Flow diagram for LST Landsat-7

For Landsat-8

The approach to the proposed work to estimate LST is shown in the Figure

3.10. This technique can only be used to process Landsat-7 (band 6) and Landsat-8 data (band 10) is used respectively to estimate brightness temperature band (4-3) for Landsat-7 and band (5-4) for Landsat-8 are used to calculate NDVI.

The steps involved in the proposed work are detailed in the following literature.

Step1

1. The satellite data products were geometrically corrected dataset.
2. The metadata of the satellite images is presented in Table
3. The first step of the proposed work is to convert the DN (Digital Number) values of band10 to at-sensor spectral radiance using the following equation:

$$L\lambda = \frac{(Lmax - Lmin) \times Qcal}{(Qcalmax - Qcalmin)} + Lmin - Qi \quad .....(4)$$

Where,

Lmax is the maximum radiance (Wm-2sr-1µm-1)

Lmin is the minimum radiance (Wm-2sr-1µm-1)

Qcal is the DN value of pixel

Qcal max is the maximum DN value of pixels

Qcal min is the minimum DN value of pixels

Oi is the correction value for band 10

Step 2

After converting DN values to at-sensor spectral radiance, the TIRS band data should be converted to brightness temperature (BT) using the thermal constants given in metadata file and the following equation

$$BT = \frac{K2}{\ln\left[\left(\frac{K1}{L\lambda}\right)+1\right]} - 273.15 \quad .....(5)$$

Where K1 and K2 are the thermal constants of TIR band 10 which can be identified in the metadata file associated with the satellite image. To have the results in Celsius, it is necessary to revise by adding absolute zero which is approximately equal to- 273.15.

Table 4

Variable	Description	Value
K1K2	Thermal constants, Band 10	774.8853 1321.0789
LmaxLmin	Maximum and Minimum values of Radiance, Band10	22.00180 0.10033r
Qcalmax Qcalmin	Maximum and Minimum values of Quantize Calibration, Band 10	65535 1
Oi	Correction value, Band10	0.29

Since the atmosphere in our research area is comparatively dry and therefore, the range of water vapor values is relatively small, the atmospheric effect is not taken into consideration in retrieving the LST

Step 3

NormalizedDifference Vegetation Index (NDVI) is essential to identify different land cover types of the study area. NDVI ranges between -1.0 to +1.0. NDVI is calculated on per-pixel of the images using the formula.

$$NDVI = \frac{(NIR-RED)}{(NIR+RED)} \quad .....(6)$$

Step 4

Next step is to calculate proportional vegetation (Pv) from NDVI values obtained in step3. This proportional vegetation gives the estimation of area under each land cover type. The vegetation and bare soil proportions are acquired from the NDVI of pure pixels. Values of NDVIv = 0.5 and NDVIs = 0.5 were proposed to apply in global conditions While the value for vegetated surfaces (NDVIv = 0.5) may be too low in some cases, for higher resolution data over agricultural sites, NDVIv can reach 0.8 or 0.9. Pv can be calculated using the equation:-

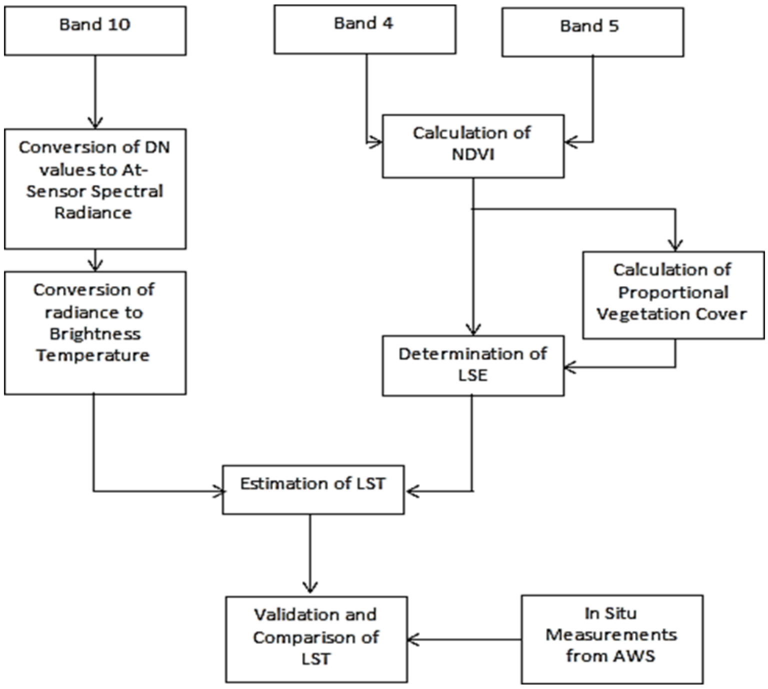

Fig 3: Flow diagram for LST Landsat-8

Step 5

Calculation of land surface emissivity (LSE) is required to estimate LST since, LSE is a proportionality factor that scales the black body radiance (Plank's law) to measure emitted radiance and it is the ability of transmitting thermal energy across the surface into the atmosphere. At the pixel scale, natural surfaces are heterogeneous in terms of variation in LSE. In addition, the LSE is largely dependent on the surface roughness, nature of vegetation cover etc.

$$\varepsilon\lambda = \varepsilon v\lambda Pv + \varepsilon s\lambda(1 - Pv) + C\lambda \quad .....(7)$$

where εv and εs are the vegetation and soil emissivities respectively, and C is the surface roughness taken as a constant value of 0.005[16]. The emissivity of water bodies is utmost stable in comparison with land surfaces. Since the emissivity depends on the wavelength, the NDVI threshold method (NTM) [17] can be used to estimate the emissivity of different land surfaces in the 10-12 µm range.

$$\begin{cases} \varepsilon_{s\lambda}, & NDVI < NDVI_s \\ \varepsilon_{s\lambda} P_v + \varepsilon_{s\lambda}(1 - P_v) + C_\lambda, & NDVI_s \le NDVI \le NDVI_v \\ \varepsilon_{s\lambda} + c_\lambda, & NDVI > NDVI_v \end{cases} \quad \varepsilon\lambda=$$

The average emissivity of four major land cover types can be considered in Band 10 as, when the NDVI is less than 0, it is classified as water, and the emissivity value of 0.991 is given, for NDVI values between 0 and 0.2, it is considered that the land cover type is soil, and the emissivity value of 0.966 is assigned, values between 0.2 and 0.5 are considered as mixture of soil and vegetation cover and equation (6) is applied to calculate the emissivity. In the last case, when the NDVI value is greater than 0.5, it is considered as vegetation cover, and the value of 0.973 is assigned.

Step6:

The final step is to calculate LST using brightness temperature (BT) of band 10 and LSE derived from Pv and NDVI [18]. LST can be retrieved using the equation

$$T_s = \frac{BT}{\{1 + [(\lambda BT/\rho) ln\varepsilon_\lambda]\}} \quad .....(8)$$

Where, Tsis the LST in Celsius (° C), BT is at- sensor BT (°C), λ is the average wave length of band 10, ελ is

the emissivity calculated from equation (6) and ρ is $(hx\frac{\varepsilon}{\sigma})$ which is equal to 1.438 x 10^{-2} m K in which, σ is the Boltzmann constant (1.38 x 10^{-23} J/K), *h* is Plank's constant (6.626 x10^{-3} and *c* is the velocity of light (3x10^8 m/s).

$$T_s = \frac{K_2}{1n\left(\frac{\varepsilon_{NB} K_1}{R_c} + 1\right)} \quad .....(9)$$

Result and Discussion

By using all the Software and methods the value obtained of Land Surface Temperature from SEBAL Algorithm of Rice Crop of Kharif Season and Wheat Crop of Rabi Season. Maps were also preapared by using ArcGis software 10.3.

Table 5: The results from SEBAL model of LST for Rice Crop and Wheat Crop

Year	LST of Rice Crop (c)	LST of Wheat Crop(c)
2007	34.096	27.853
2008	28.542	28.676
2009	43.495	33.994
2010	39.743	30.058
2011	31.679	27.118
2012	31.913	34.793
2013	29.832	29.487
2014	30.939	27.598
2015	30.022	26.568
2016	41.184	26.804
2017	39.321	25.885
2018	33.384	29.731
2019	31.576	25.571
2020	31.622	25.198
2021	33.561	23.806

Land Surface Temperature (LST) was found to be maximum 43.495 0C.in 2009 and minimum 28.542 0C in 2008 by the SEBAL algorithm for Rice Crop and Surface Temperature (LST) for Wheat Crop was found to be maximum 34.793 0C in 2012 and minimum 23.806 0C in 2021. Maps are shown in below figure.

LST map of the study area

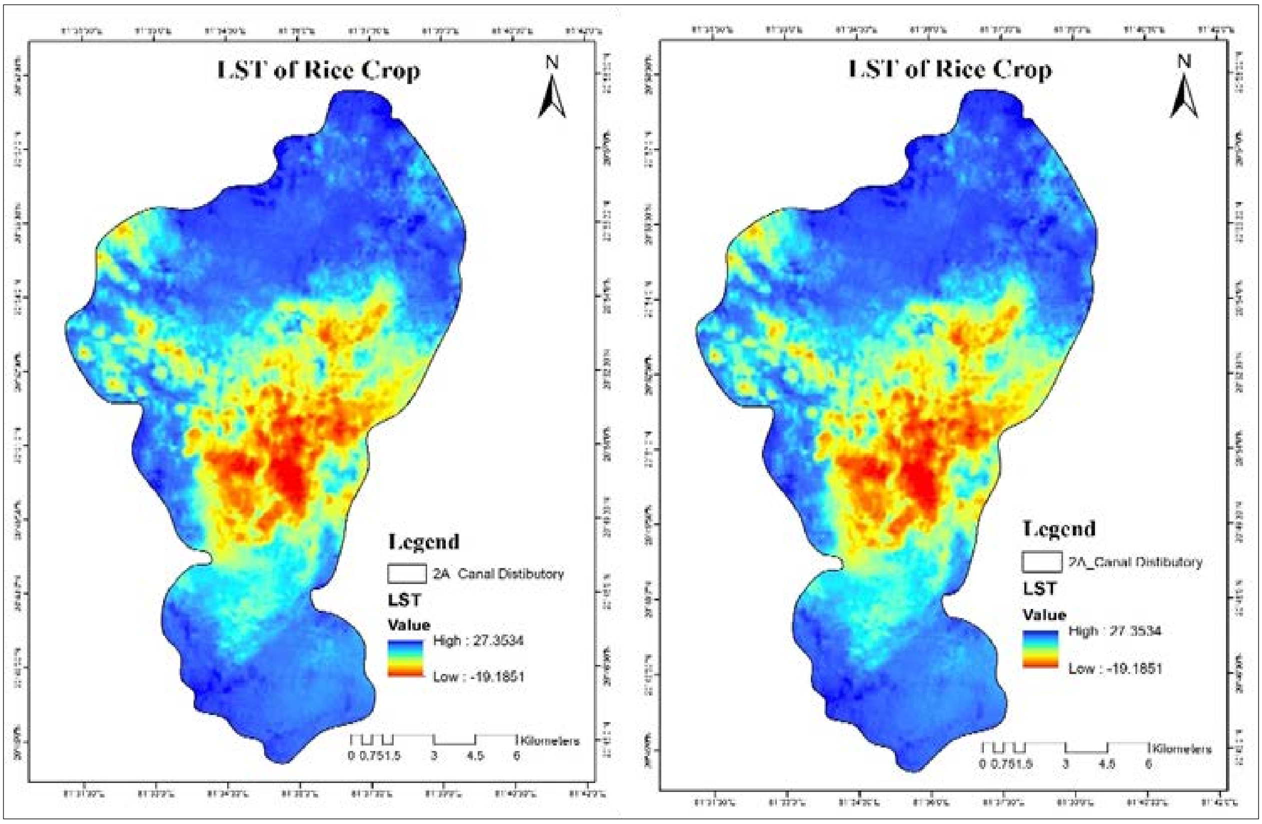

Fig 4: Maximum and minimum land surface temperature of Rice Crop

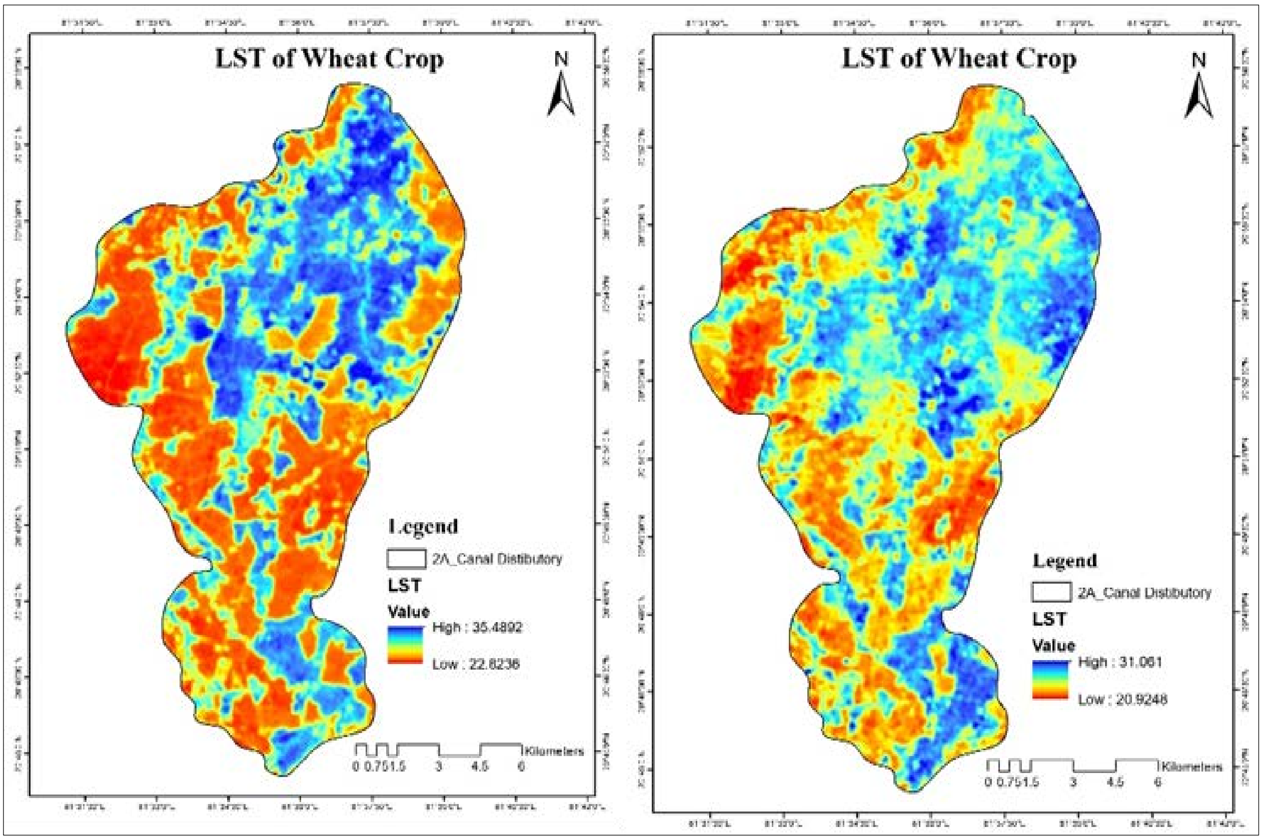

Fig 5: Maximum and minimum land surface temperature of Wheat Crop

Conclusion

The importance of Land Surface Temperature is being increasingly recognized, because many of the changes on the Earth's surface caused by changes in temperature. In the present study, using Landsat 7 and 8 Image of 2A distributary of Mahanadi canal Command which is situated in Dhamtari district of Chhattisgarh state of India, land surface temperature had been calculated by using both the OLI and TIRS bands. The results obtained from present study revealed that Land Surface Temperature (LST) was found to be maximum 43.495 ^{0}C. in 2009 and minimum 28.542 ^{0}C in 2008 by the SEBAL algorithm for Rice Crop and Surface Temperature (LST) for Wheat Crop was found to be maximum 34.793 ^{0}C in 2012 and minimum 23.806 ^{0}C in 2021.

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