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CONTENT

Land Surface Temperature (LST) Calculation processes with Landsat 8

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ABSTRACT

Land Surface Temperature (LST) refers to the thermodynamic temperature of the Earth's surface, defined by the radiative temperature radiated from that surface. It provides insights into surface energy fluxes and atmospheric interactions. Land Surface Temperature (LST) exhibits significant variability in both spatial and temporal dimensions, attributable to the variety of climatic influences, land cover, soil and vegetation moisture content, surface radiative characteristics, and topographical features. Satellite data offers benefits over in situ measurements, including worldwide accessibility, uniformity, and geographically dispersed data collection, resulting in a cost-effective and efficient data stream. LST is extensively utilized across several domains, such as agriculture, phenological development, planting depth recommendations, yield forecasting models, weather and climate surveillance, heatwave assessment, urban heat island effect analysis, and environmental impact evaluation. Calculating Land Surface Temperature (LST) with Landsat 8 thermal bands necessitates image preprocessing, rectification, geocoding, and analysis. Factors such as vegetation and radiated radiation are essential for calculating land surface temperature (LST).

Obtaining LST necessitates image preprocessing, correction, geocoding, and analysis. Comprehending the evolution and distribution of LST is crucial for climate change monitoring, agricultural management, land cover alterations, and several other uses.

Keywords – Land Surface Temperature (LST), Land Surface Emissivity (LSE) Remote Sensing, NDVI, Landsat, QGIS.

INTRODUCTION

The Land Surface Temperature (LST) denotes the thermodynamic temperature of Earth's surface and defines the radiative temperature emitted by the surface, providing insights into surface energy fluxes and atmospheric interactions (“Land Surface Temperature Technical Specification,” n.d.).

The Earth's surface absorbs solar radiation, resulting in land heating, while the emitted temperature varies due to the variability of climatic forces, land cover, soil and vegetation moisture content, surface radiative characteristics, and terrain. Consequently, LST exhibits significant variability in both spatial and temporal dimensions (Prata et al., 1995). Due to significant spatio-temporal variability, satellite-derived land surface temperature (LST) has several advantages over in situ observations, including worldwide accessibility, consistency, and geographical distribution, resulting in a cost-effective and efficient data stream.

Land surface temperature (LST) is an essential element of Earth's climate and several physical, chemical, and biological processes. Considering that climate change is a worldwide warming phenomena, it is imperative to employ space technology for the monitoring of land surface temperature (LST). Urban warming, however, encompasses an extra phenomenon known as the urban heat island effect. Land surface temperature is correlated with several biophysical and demographic factors, necessitating that quantitative estimations consider this relationship.

The data shown reflects the temperature as observed from a satellite's perspective. The "surface" refers to what the sensor observes as it views the ground through the atmosphere, such as the canopy top in planted regions, dirt in non-vegetated areas, or rooftops in urban settings. Consequently, Land Surface Temperature differs from the air temperature reported in daily weather forecasts. LST can offer insights into several applications, including evaporation monitoring, climate change research, soil moisture assessment, vegetation analysis, and urban studies, among others. Miralles et al. (2011), Intergovernmental Panel on Climate Change et al. (2021), Merlin et al. (2008), Mantey et al. (2014), Voogt and Oke (2003), Land Surface Temperature Technical Specification (n.d.)

USAGE OF LST

LST is extensively utilized throughout several domains nowadays. Typical applications of LST are as follows.

Agriculture

<u>Crop Stress Monitoring:</u> Utilizing Planet Land Surface Temperature as input in energy balance-based evaporation models facilitates the early detection of crop stress, enabling timely intervention.

<u>Phenological development:</u> Land Surface Temperature (LST) can serve as an input for Growing Degree Days. Growing degree days serve as a meteorological metric for evaluating crop maturation. Agricultural producers utilize a metric of thermal accumulation to forecast the rates of plant and pest growth in relation to the timing of crop maturation. The benefit of LST-based GDD is its capacity to precisely assess crop conditions, offering insights into crop growth and development, rather than depending exclusively on environmental circumstances based on air temperature.

<u>Seeding Depth Prescription:</u> High resolution LST shows potential for comprehending within-field heterogeneity, therefore facilitating planting depth prescriptions to enhance uniformity of emergence and plant stand according to local environmental, soil, and management variables.

<u>Yield forecasting model:</u> When combined with Soil Water Content and Vegetation Optical Depth, Land Surface Temperature can be utilized in yield forecasting models. Thermal anomalies adversely affect yields throughout

various stages of the growing season, becoming it a crucial factor in regional yield forecast models.

Weather and Climate Monitoring¶

Monitoring circumstances across years and decades, Land Surface Temperature data establishes a foundational comprehension of typical and atypical conditions for each specific location.

Heatwave monitoring: The land surface temperature of the planet may monitor arid and elevated thermal conditions. The correlation between soil moisture and temperature signifies the intensity and scope of drought conditions and their impact on agriculture, ecosystems, and human populations.

Urban Heat Island: Urban areas exhibit elevated temperatures relative to their rural counterparts. Planet Land Surface Temperature can be pivotal in identifying metropolitan areas most affected by heat and assist governments and municipal administrations in determining necessary solutions.

Environmental Impact monitoring¶

Quantify the effect of restoration initiatives: Land Surface Temperature can be utilized to monitor landscape alterations resulting from intervention operations and the consequent effects of these changes on the region's climate.

The Land Surface Temperature can be estimated using the thermal bands of Landsat 8. It necessitates the application of a series of equations via a raster image calculator utilizing QGIS.

This tutorial demonstrates the calculation of Land Surface Temperature (LST) with the Landsat 8 bands. Specifically, band 10 serves as the temperature band, whereas bands 4 and 5 are utilized to compute the Normalized Difference Vegetation Index (NDVI).

Land Surface Temperature (LST) is the radiative skin temperature of the terrestrial surface obtained from solar radiation. It is a fundamental factor influencing the terrestrial thermal dynamics, as it regulates the effective radiating temperature of the Earth's surface. LST is associated with various facets of geoscience, making the comprehension of its evolution and global distribution crucial for monitoring climate change, crop management, land cover alterations, and numerous other applications (Voogt and Oke, 2003; Xiao et al., 2008; Franzpc, 2019).

Retrieving LST necessitates image preprocessing, rectification of distortions from satellite image acquisition, evaluation of geometric and temporal compatibility with other information sources through geocoding and projection onto a suitable system, and subsequent image analysis. Sensors quantify digital values that must be converted into radiance and subsequently into brightness temperature utilizing established methodologies. Vegetation is a significant characteristic that affects land surface temperature (LST). Brightness temperature is utilized to compute the Normalized Difference Vegetation Index (NDVI), an indicator of vegetation greenness. The calculation of NDVI facilitates the determination of the plant cover proportion in the specified region. The last element in calculating Land Surface Temperature (LST) is Land Surface Emissivity, which is used to ascertain emitted radiance based on soil, plant, and surface roughness values. These variables allow the acquisition of land surface temperature with the spatial resolution afforded by the sensors (Twumasi et al., 2021).

DATA COLLECTION

An imagine from Landsat 8 (Operational Land Imager), covering the northwestern region of Turkey, was obtained from the United States Geological Survey Earth Explorer's free online data services for land surface temperature (LST) study (U.S. Geological Survey, 2024a). The image was obtained with less than 10% cloud cover in June 2024 (Table 1).

Table 1: Landsat images used in the LST mapping of Tekirdag

LANDSAT SCENE ID	Sensor	Resolution	Path/Row	Date
LC81810322024153LGN00	Landsat 8	30 m	181/032	06.01.2024

Source: (U.S. Geological Survey, 2024a).

IMAGE PROCESSING

Three tasks were executed to process the images. These encompassed image preprocessing and correction. In picture pre-processing, both visual and digital image processing were conducted, and prior to this, images were loaded into QGIS 3.34 software for subsequent processing. Thermal Infrared band 10 was selected for subsequent study.

IMAGE RECTIFICATIONS

Image rectifications were executed to amend data distortion potentially arising from the image gathering procedure, utilizing the Impact toolkit created by the European Union Joint Research Centre. To guarantee precise identification of time variations and geometric congruence with other informational sources, images were geocoded to the coordinate and mapping system of the national topographic maps. Each image were projected to the Universal Transverse Mercator (UTM) coordinate system, zone 35 North.

IMAGE ANALYSIS

The algorithm was created in QGIS 3.34. In this study Landsat 8 Thermal Infrared band (Band 10) was used to estimate brightness temperatures and bands 4 (Red) and 5 (Infrared) were used for calculating the NDVI. The LST retrieval formulas were taken from the USGS web page for retrieving the top of atmospheric (TOA) spectral radiance (U.S. Geological Survey, 2024b). The LST was retrieved following the steps of Figure 1.

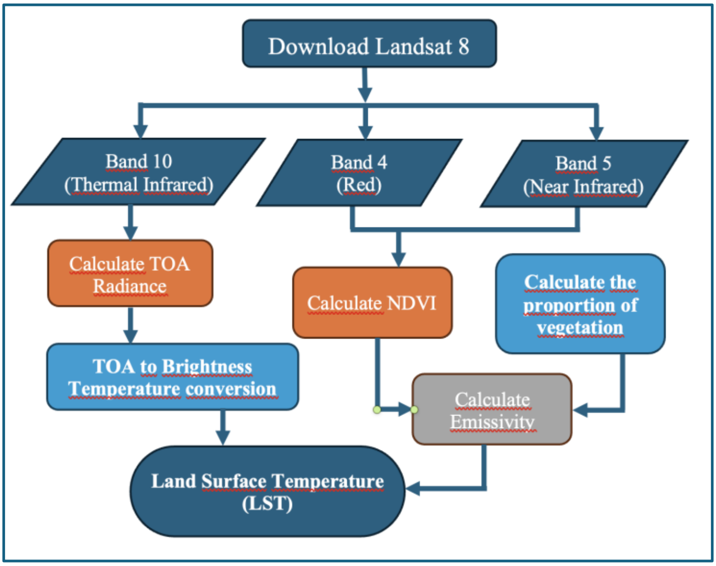

Figure 1: Flowchart for LST processing.

CALCULATİON OF TOA (TOP OF ATMOSPHERİC)

Top of Atmosphere (TOA) Reflectance is a unitless measurement which provides the ratio of radiation reflected to the incident solar radiation on a given surface. It that can be computed from satellite measured spectral radiance using the mean solar spectral irradiance and the solar zenith angle (Marino, 2024). Landsat Level-1 data can be converted to TOA spectral radiance using the radiance rescaling factors in the MTL file. The metadata for the equations is contained in the Text documentation in the Landsat 8 data folder downloaded from the U.S. Geological Survey EarthExplorer web site.

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

where:

L_λ = TOA spectral radiance (Watts/(m^2 * srad * µm))

M_L =Band-specific multiplicative rescaling factor from the metadata,

A_L=Band-specific additive rescaling factor from the metadata

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

In the QGIS application, the following equation will be written in the calculation of TOA with the Raster Calculator tool. The raster image obtained as a result of the TOA process is shown in figure 3.

TOA = 0.0003342 * “Band 10” + 0.1

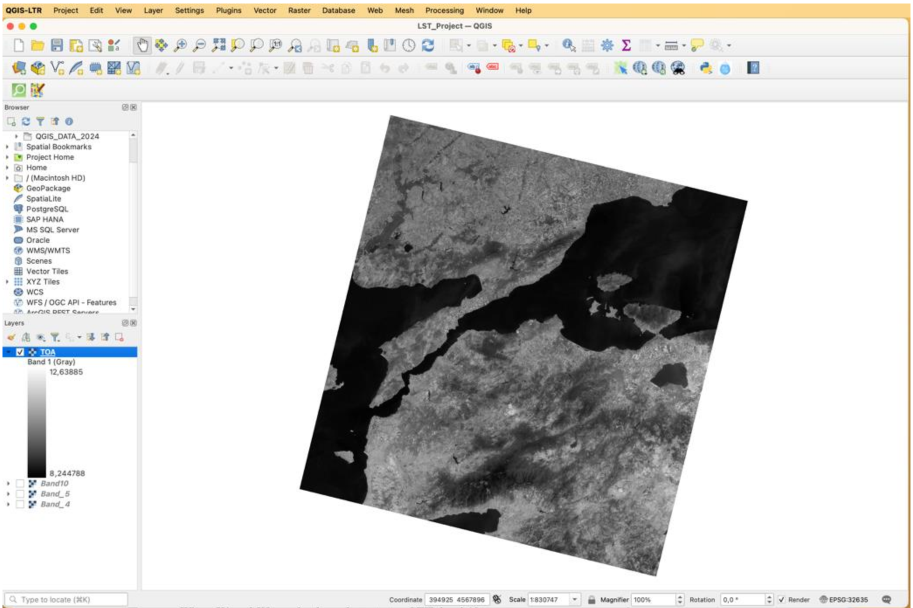

Figure 2: Result of the TOA (Top of Atmospheric) calculation.

CONVERSİON TOA TO BRİGHTNESS TEMPERATURE

Thermal band data can be converted from spectral radiance to top of atmosphere brightness temperature using the thermal constants in the MTL file:

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

where:

B_T = Top of atmosphere brightness temperature (K)

L_λ =TOA spectral radiance (Watts/(m2 * srad * µm))

K_1 = Band-specific thermal conversion constant from the metadata

K_2 = Band-specific thermal conversion constant from the metadata

In the QGIS application, the following equation will be written in the calculation of Conversion TOA to Brightness Temperature with the Raster Calculator tool. Therefore, to obtain the results in Celsius, the radiant temperature is adjusted by adding the absolute zero (approx. -273.15°C).

BT = (1321.0789 / Ln ((774.8853 / “%TOA%”) + 1)) – 273.15

The satellite data products were geometrically corrected data set. The metadata of the satellite images is presented in Table 2 and the result shown in figüre 4.

Table 2: Metadata of the Landsat 8 images

Metadata Variable	Description	Value
M_L	RADIANCE MULT BAND 10	0.0003342
A_L	RADIANCE ADD BAND 10)	0.10000
K_1	CONSTANT BAND 10	774.8853
K_2	CONSTANT BAND 10	1321.0789

Source: (U.S. Geological Survey, 2024a).

CALCULATE THE NDVI

The normalized difference vegetation index (NDVI), which is derived from remote-sensing (satellite) data, is closely linked to drought conditions. To determine the density of green on a patch of land, the distinct colors (wavelengths) of visible and near-infrared sunlight reflected by the plants are observed; red and near-infrared bands i.e . Band 4 and Band 5 respectively were used for calculating the Normal NDVI. The importance of estimating the NDVI is essential since the amount of vegetation present is an important factor and NDVI can be used to infer general vegetation condition. The calculation

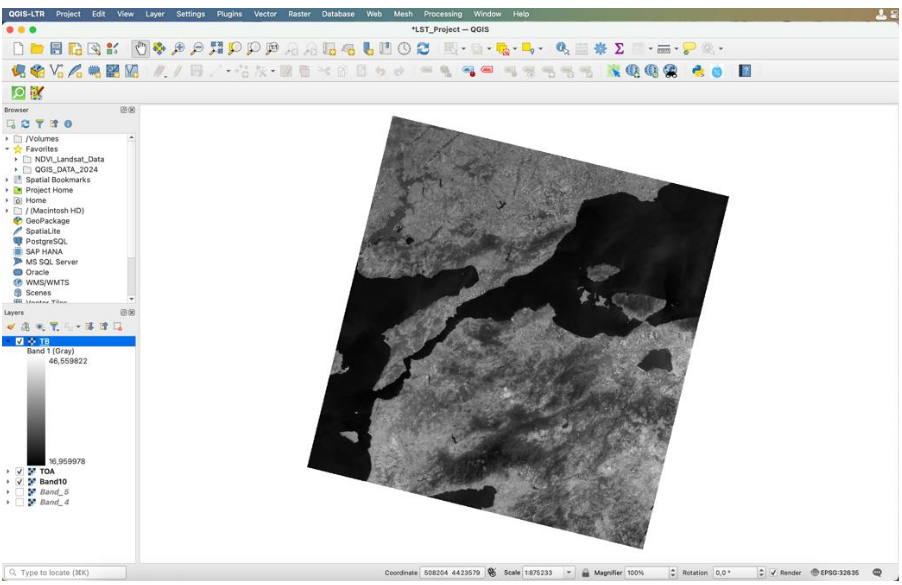

Figure 3: Result of the BT (brightness temperature) calculation.

of the NDVI is important because, afterward, the proportion of the vegetation (P_V) should be calculated, and they are highly related with the NDVI, and emissivity (ε) should be calculated, which is related to the P_V.

$$NDVI = \frac{NIR(Band\ 5) - Red\ (Band\ 4)}{NIR(Band\ 5) + Red\ (Band\ 4)}$$

Where NIR represents the near-infrared band (Band 5) and R represents the red band (Band 4). This formula is written with the Raster Calculator tool as follows and the process is performed (Fig. 4).

NDVI = (Band 5 – Band 4) / (Band 5 + Band 4)

CALCULATE THE PROPORTİON OF VEGETATİON

Proportion of vegetation (Vegetation Fraction) is defined as the percentage of vegetation occupying the ground area in vertical projection. Changes in vegetation cover directly impact surface water and energy budgets through plant transpiration, surface albedo, emissivity, and roughness. The proportion of vegetation P_V is closely related to NDVI values for vegetation and soil. In this study, P_V was estimated following the NDVI traditional method (Aman, et al., 1992, Rouse, et al., 1974)

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

Where $NDVI_v$ and $NDVI_s$ are Maximum and Minmum NDVI respectively representing NDVI of Vegetation and NDVI of soil respectively (in our application, the minimum value is calculated as -0.26334 and the maximum value is calculated as 0.653719).

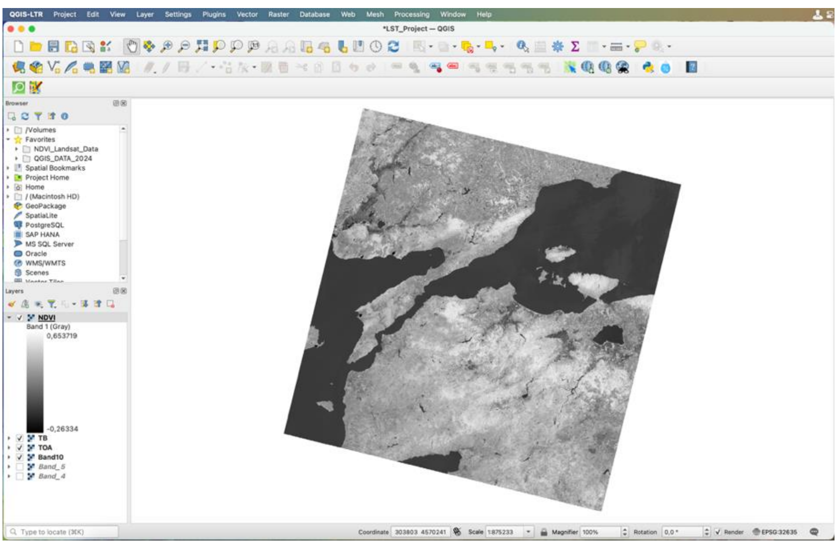

Figure 4: Result of the NDVI calculation.

This calculate the proportion of vegetation (P_v) formula is written with the Raster Calculator tool as follows and the process is performed.

P_v = ((“NDVI@1” – 0.26334) / (0.653719 – 0.26334)) ^ 2

Usually the minimum and maximum values of the NDVI image can be displayed directly in the image, otherwise you must open the properties of the raster to get those values (Fig.5).

Calculate the land surface emissivity

The emissivity (ε) values for the land cover classes are provided in the following table (values used in this tutorial are only indicative, because emissivity of every material should be obtained from field survey) (Weng et al., 2004, “Tutorial: Estimation of Land Surface Temperature With Landsat And ASTER,” n.d.):

Land surface emissivity (LSE). Average emissivity of an element of the surface of the Earth calculated from measured radiance and land surface

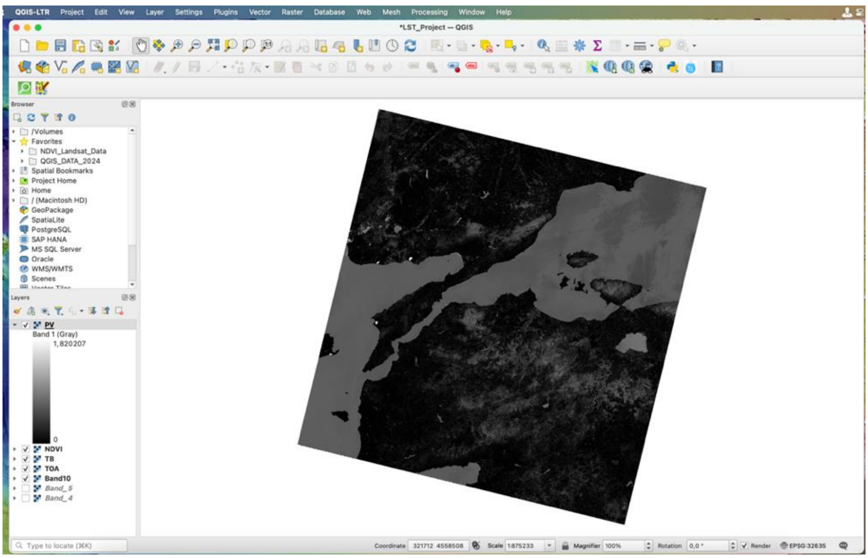

Figure 5: Result of the Pv (Proportion of vegetation) calculation.

temperature. The land surface emissivity (LSE (ε)) must be known in order to estimate LST, ince the LSE is a proportionality factor that scales blackbody radiance to predict emitted radiance, and it is the efficiency of transmitting thermal energy across the surface into the atmosphere. The determination of the ground emissivity is calculated conditionally as suggested (Jimenez-Munoz,, et al., 2006, Sobrino, J.A. and Raissouni, 2000, Sobrino, et al., 2004).

$$\varepsilon_{\lambda} = \varepsilon_{V\lambda} P_V + \varepsilon_{S\lambda}(1 - P_V) + C_{\lambda}$$

where ε_v and ε_s are the vegetation and soil emissivities respectively, and C is the surface roughness taken as a constant value of 0.005. 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) can be used to estimate the emissivity of different land surfaces in the 10-12 μm range. Additionally, the spectral range of Band 10 of Landsat 8 is suitable in this range. At this wavelength range, the emissivity could be modeled as follows (Weng et al., 2004):

$$\varepsilon_\lambda = \begin{cases} \varepsilon_{S\lambda}, & NDVI < NDVI_S \\ \varepsilon_{V\lambda} P_V + \varepsilon_{S\lambda}(1 - P_V) + C_\lambda, & NDVI_S \le NDVI \le NDVI_V \\ \varepsilon_{V\lambda} P_V + C_\lambda, & NDVI > NDVI_{VS} \end{cases}$$

The differences between the retrieved LSTs and the air temperatures and details on the stations are presented in Table 3 (Avdan & Jovanovska, 2016).

Table 3. Emissivity of representative terrestrial materials for LANDSAT 8 TIRS Band 10.

Terrestrial material	Water	Building	Soil	Vegetation
Emissivity	0.991	0.962	0.966	0.973

Source: (Avdan & Jovanovska, 2016).

However for this study the mean NDVI value is between 0 and 0.2 therefore the emissivity value of 0.996 was assigned.

The Calculate Emissivity (ε) formula is written with the Raster Calculator tool as follows and the process is performed (Fig.6).

$\varepsilon = 0.004 * P_v + 0.986$

Calculate Land Surface Emissivity (EM) using the Fraction of Vegetation (FV). The 0.004 coefficient represents the emissivity variation due to vegetation, and the 0.986 represents the base emissivity for other surfaces (Ridho, 2024, Li et al., 2012).

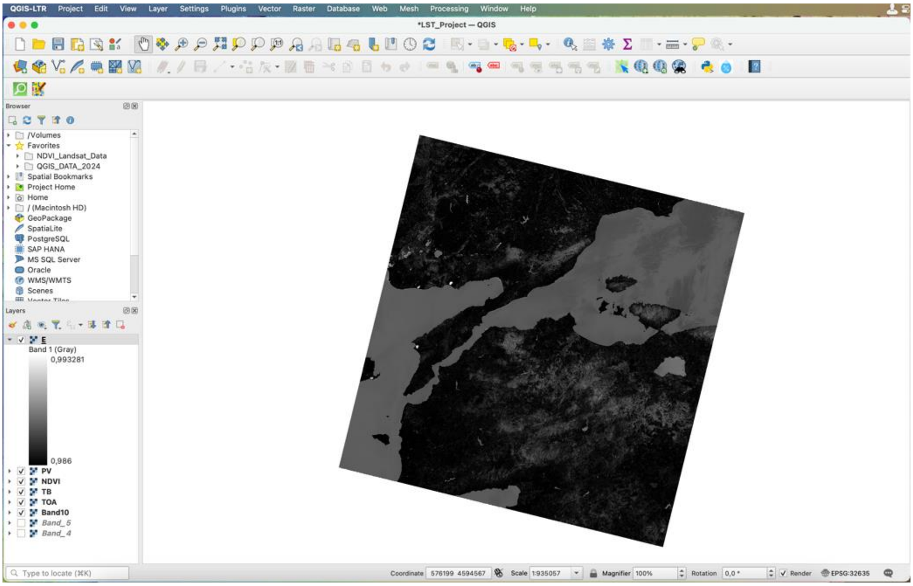

Figure 6: Result of the E (emissivitty) calculation.

CALCULATE THE LAND SURFACE TEMPERATURE

The emissivity corrected land surface temperatures (S_t) were calculated as follows (Weng, et al. 2004, Saha et al., 2023):

$$S_t = \frac{B_T}{1 + \left[\left(\frac{\lambda * B_T}{\rho}\right) * \ln_{\varepsilon_\lambda}\right]}$$

where:

B_T = Top of atmosphere brightness temperature (K)

λ = wavelength of emitted radiance from Landsat-8 TIRS band 10 (λ = 10.895) (Sholihah & Shibata, 2019) (Tables 4).

$\rho = h\frac{c}{\sigma} = 1.4388 * 10^{-2} mK$ = 14388 µK

h = Planck's constant = $6.626*10^{-34}$ J s

σ = Boltzmann constant = $1.38*10^{-23}$ J/K

c = velocity of light = $2.998*10^{8}$ m/s

Table 4. Wavelength of Landsat 8 band 10.

Landsat 8 bands	**Wavelength (micrometers)**	**Resolution (meters)**
Band 1 - Coastal aerosol	0.43 - 0.45	30
Band 2 - Blue	0.45 - 0.51	30
Band 3 - Green	0.53 - 0.59	30
Band 4 - Red	0.64 - 0.67	30
Band 5 - Near Infrared (NIR)	0.85 - 0.88	30
Band 6 - SWIR 1	1.57 - 1.65	30
Band 7 - SWIR 2	2.11 - 2.29	30
Band 8 - Panchromatic	0.50 - 0.68	15
Band 9 - Cirrus	1.36 - 1.38	30
Band 10 - Thermal Infrared (TIRS) 1	10.60 - 11.19	100 (resampled to 30)
Band 11 - Thermal Infrared (TIRS) 2	11.50 - 12.51	100 (resampled to 30)

The LST (S_t) formula is written with the Raster Calculator tool as follows and the process is performed.

LST = (BT / (1 + (10.895 * BT / 14388) * Ln(ε)))

Finally, the land surface temperature map was produced in QGIS.

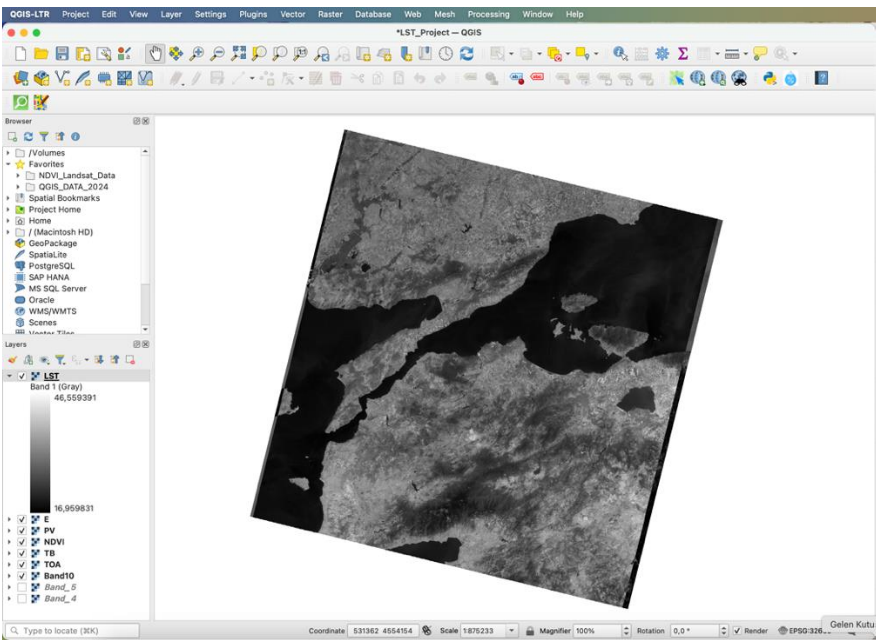

Figure 7: Result of the LST calculation.

As a final process, the LST map is colored according to the temperature values, and the objects (scale, legend, etc.) are added to the map (Fig. 8).

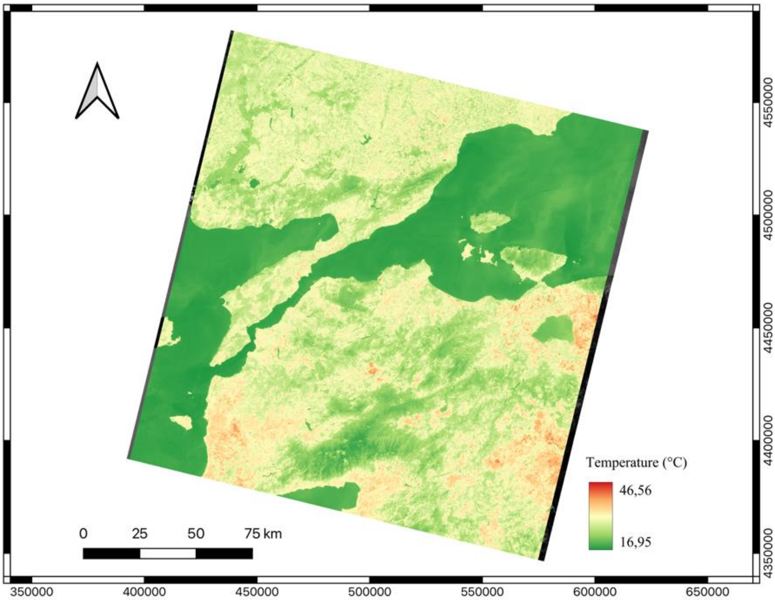

Figure 8: LST map example.

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