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Mapping Land Surface Temperature: Using Digital Image Processing Technique for Natri, Asendabo and Dedo Weredas in Jimma Zone/Oromia/ Ethiopia

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Abbreviations: ^{0}C: Degree Centigrade; BT: Temperature Brightness; DNs: Digital Numbers; ERDAS: Earth Resource Data Analysis System; GIS: Geographic Information System; KTs: Kinetic Temperatures; LST: Land Surface Temperature; LSTM: Land Surface Temperature Mapping; m: Meter; NDVI: Normalized Difference Vegetation Index; NIR: Near Infrared; OLI: Operational Landsat Imageries; RS: Remote Sensing; RTs: Radiant Temperatures; TIR: Thermal Infrared; TIRS: Thermal Infrared Satellite; TOA: Top of Atmosphere; USGS: United State Geological Survey; VIS: Visible; WOMSC: Western Oromia Meteorological Service Center

Introduction

Land surface temperature (LST) is defined as the temperature felt when the land surface is touched with the hands or skin temperature of the ground [1]. Earth surface temperature, including water surface temperature and land surface temperature (LST), refers to the temperature of the critical layer by which the earth surface interacts with the atmosphere. Earth surface temperature is an important parameter reflecting earth surface environment and is widely used in several research fields such as climate change, agricultural drought monitoring and urban heat island effect [2].

Although remote sensing is recognized as a powerful tool in the collection, analysis, and modeling of environmental data, less attention has been given to the use of thermal infrared (TIR) remote sensing. With the launch of the NASA Terra suite of Earth remote sensing instruments in 1999, which included TIR sensors, thermal data are poised to become a major source of quantitative and qualitative information on land surface processes and for their characterization, analysis, and modelling (Quattrochi & Luvall, 2004) as cited in [3]. There are two fundamental reasons why TIR data contribute to an improved understanding of land surface processes: (a) through measurement of surface temperatures as related to specific landscape and biophysical components and (b) through relating surface temperatures with energy fluxes for specific landscape phenomena or processes [3].

TIR data from Remote Sensing satellites has been widely and beneficially used in many applications. One major advantage of TIR data is that it offers information on the emissive properties of the terrain features that is complementary to the information on the reflective properties offered by the visible (VIS) and near infrared (NIR) data. Land Surface Temperature Mapping (LSTM) is a major application of the RS-TIR data. LSTM involves, deriving an accurate land use map, estimating radiant temperatures (RTs) from the TIR data and choosing and assigning appropriate emissivity values to the land use categories to estimate their kinetic temperatures (KTs) [4].

The algorithm introduced in this project paper has been developed using ERDAS IMAGINE 2015, with the Model Maker allowing us to create a model that will repeat the process automatically, and it is easy to develop a simple tool useful for doing pixel calculations. Therefore, in this paper emphasis was given to land surface temperature mapping by using the different algorithms integrating with tools within ArcGIS 10.3.1 and ERDAS EMAGINE 2015 software versions.

Objective of the Paper

The main objective of this project paper is to Map Land Surface Temperature from land sat satellite 8 OLI/TIRS image with Path 169 and 055 row.

Methods and Materials

Sources of data

In this Lab. project paper, the surface temperature measurement was carried out with the help of Landsat 8 image of 169 path and 055 row which data procured from USGS archive (https://earthexporer.usgs.gov/) Table 1 below shows the satellite data source and its description. At fast mapping of land surface temperature have been done from above mention Landsat imagery using ArcGIS10.3.1 and ERDAS EMAGINE 2015 soft wares.

Data analysis

Methods of data analysis in case of the generation of LST map the following algorithms/formulae were applied.

Conversion of satellite image to spectral radiance

Digital Number (DN) value of thermal bands that is band 10/11 in case of Landsat OLI/TIRS are converted into TOA (Top of Atmosphere) radiance using following algorithm.

$$L\lambda = ML * Qcal + A$$

Where, L = TOA spectral radiance (Watts/ (m^{2*} srad * μm));

M= Band-specific L multiplicative rescaling factor from the metadata RADIANCE_MULT_ BAND_x, where x is the band number)

A= Band-specific additive rescaling L factor from the metadata (RADIANCE_ADD_BAND_x, where x is the band number);

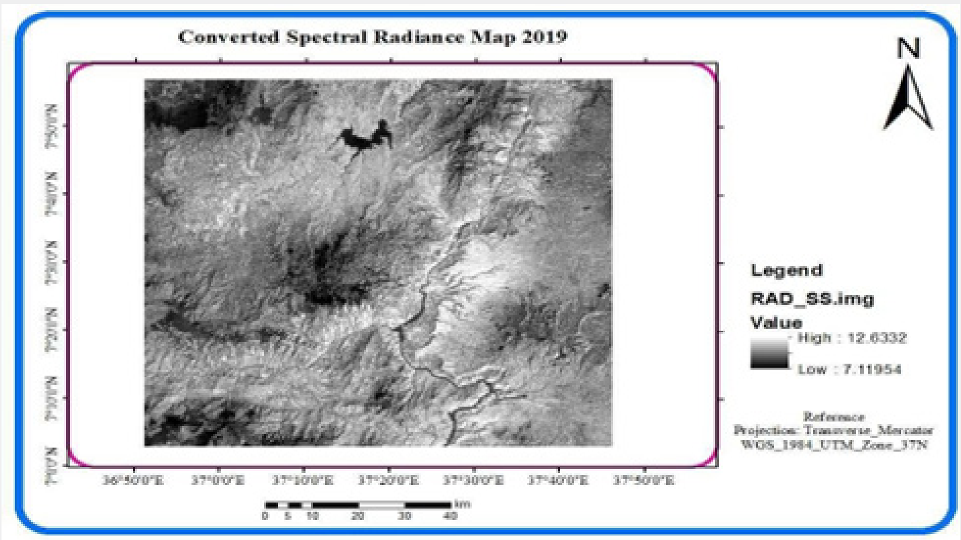

Figure 1: Spectral radiance map.

Table 1: Description of Data and its sources.

No	Satellite	Sensor	Path	Row	Date of Acquisition	Resolution	Cloud Cover (%)	Source
1	Land sat 8	OLI/TIRS	169	55	23/01/2019	30mx30m	<10	USGS website

Qcal= Quantized and calibrated standard product pixel values (DN) (Figure 1 & 2).

Conversion of spectral radiance to brightness temperature

After the digital numbers (DNs) are converted to reflection, the TIRS band data should be converted from spectral radiance to brightness temperature (BT) using the thermal constants provided in the metadata file [1].

Conversion from TOA spectral radiance to brightness temperature (T) using following formula

$$T = \frac{K2}{\left[Ln\left\{ \left(\frac{K1}{L} \right) + 1 \right\} \right]}$$

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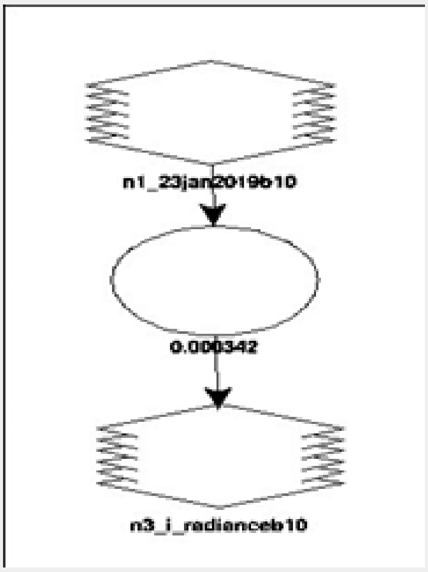

Figure 2: Model derived to convert satellite image to spectral radiance.

Where - T= At-satellite brightness temperature (K), L =TOA spectral radiance (Watts/ (m^2 * srad * μm)), K = Band-specific 1 thermal conversion constant from the metadata (K1_CONSTANT_BAND_x, where x is the band number, 10 or 11), K2 = Band-specific thermal conversion constant from the metadata (K2_CONSTANT_BAND_x, where x is the band number, 10 or 11).

Here the output is in Kelvin unit converted it into degree centigrade by sub ducting 272.15 (Figure 3 & 4).

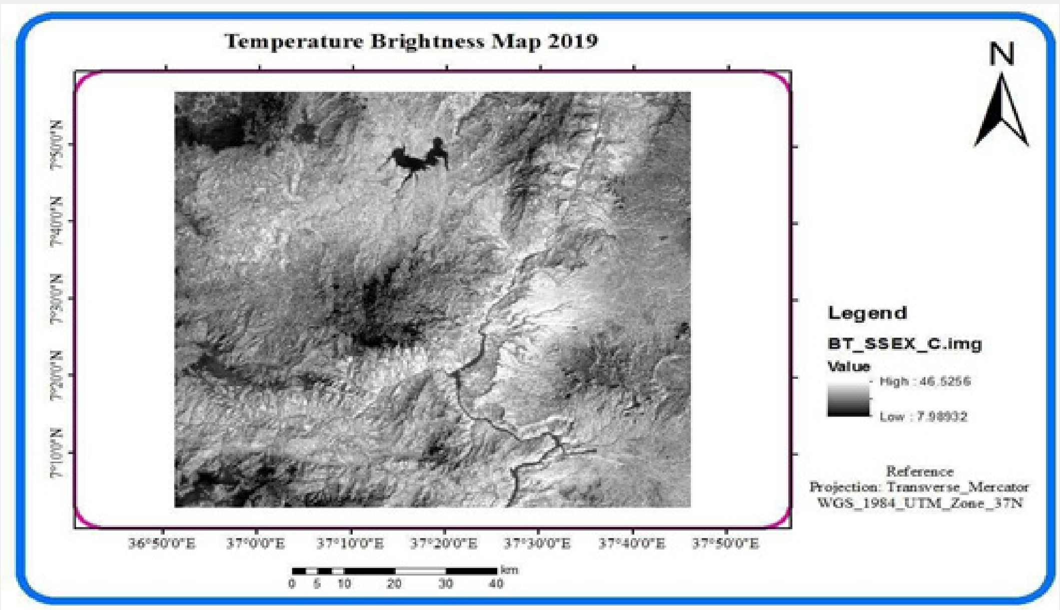

Figure 3: Map of temperature brightness.

Calculation of NDVI (Normalized Difference Vegetation Index)

Landsat visible and near-infrared bands were used for calculating the Normal Difference Vegetation Index (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 of the NDVI is important because, afterward, the proportion of the vegetation

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(PV) should be calculated, and they are highly related with the NDVI, and emissivity (E) should be calculated, which is related to the PV [1].

Calculation of NDVI (Normalized Difference Vegetation Index) using Near Infrared (NIR) bandand red band. In case land sat 8 satellite image we use band 5(Near Infrared) and band 4(Red). The algorithm stands as: -

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

(Figure 5 & 6)

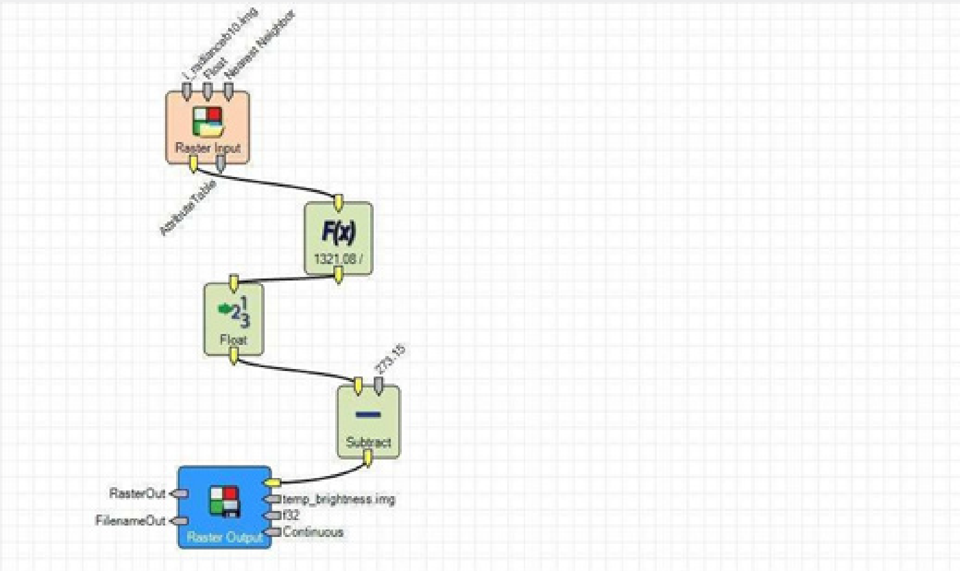

Figure 4: Model derived to convert spectral radiance band 10 image to brightness temperature.

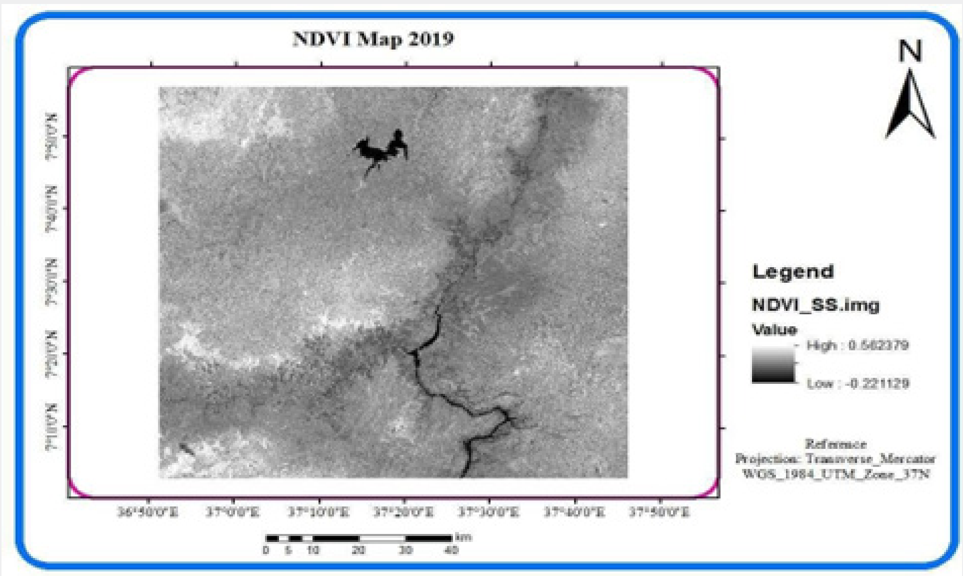

Figure 5: NDVI Map.

Calculation of vegetation proportion

According to Carlson & Ripley (1997) as cited in Das, (2015) Vegetation proportion can be derived according to using NDVI image equation below:

$$Pv = \left[\frac{(NDVI - NDV\,\mathrm{Im}in)}{(NDV\,\mathrm{Im}ax - NDV\,\mathrm{Im}in)} \right] 2$$

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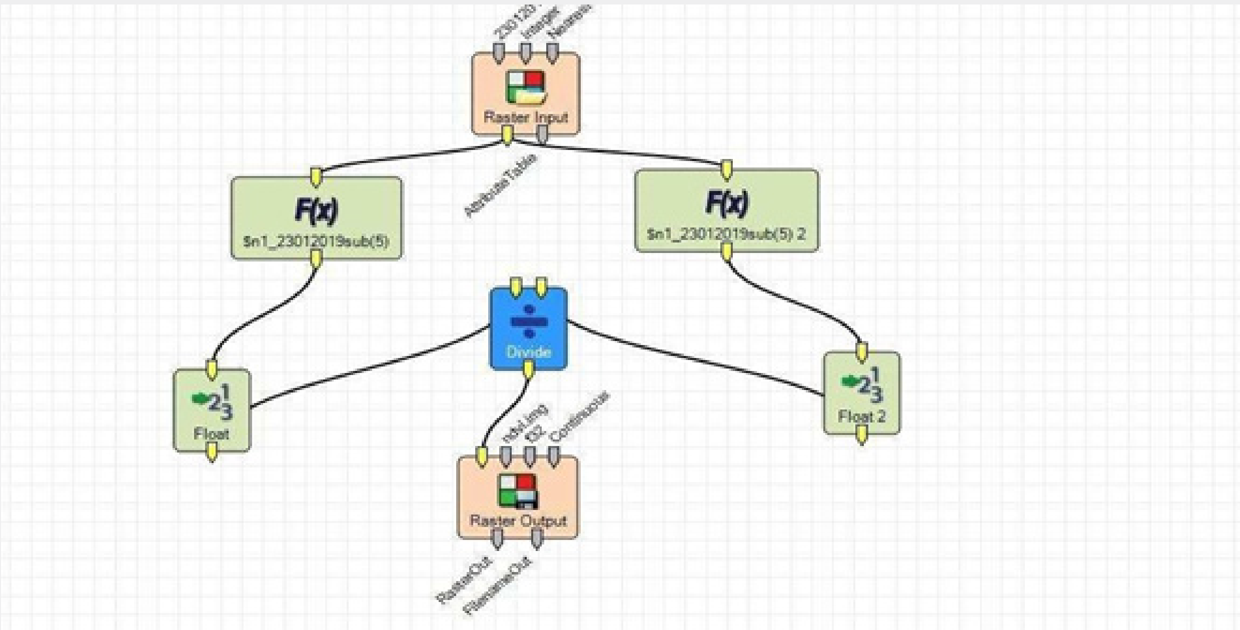

Figure 6: Model derived to calculate NDVI value.

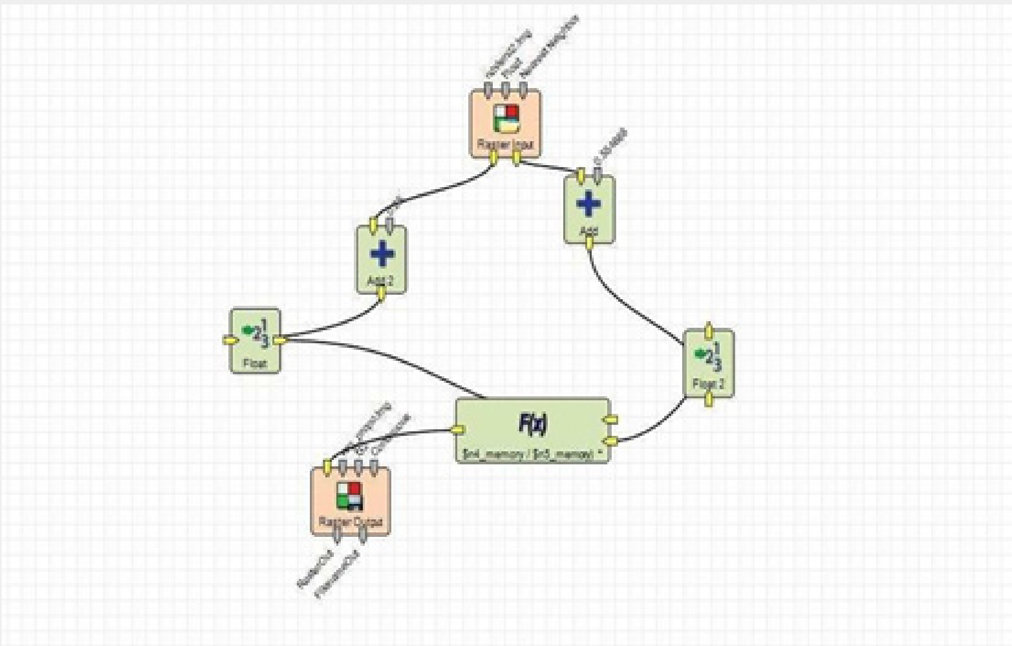

Figure 7: Model derived to calculate vegetation proportion.

Calculation of land surface emissivity

Ground emissivity is a key parameter in LST retrieval model. It uses thermal infrared remote sensing techniques, which mainly depends on the surface material structure and wavelength range of the remote sensor. Emissivity is a measure of the ability of a surface to emit energy by radiationwhich has a great influence on LST retrieval. Currently, the visible and near infrared spectra are often used for estimating ground emissivity [5].

The Calculation of Land Surface Emissivity (e) done using following equation

$$e = 0.004 * Pv + 0.986$$

where Pv is the Proportion of Vegetation

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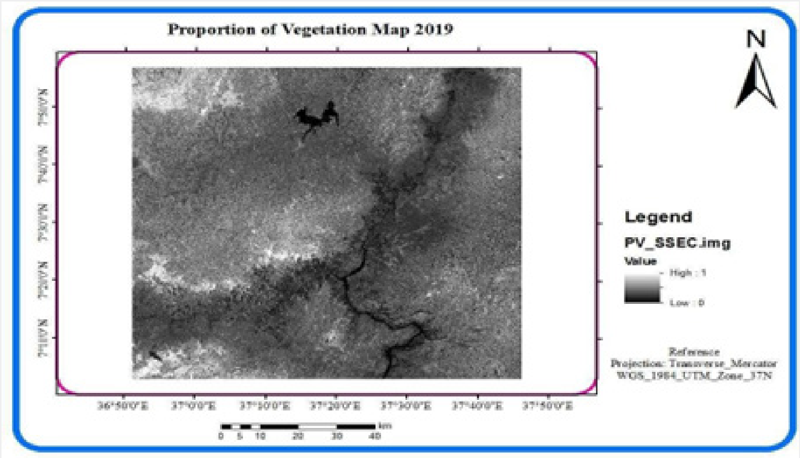

Figure 8: Proportion of vegetation map.

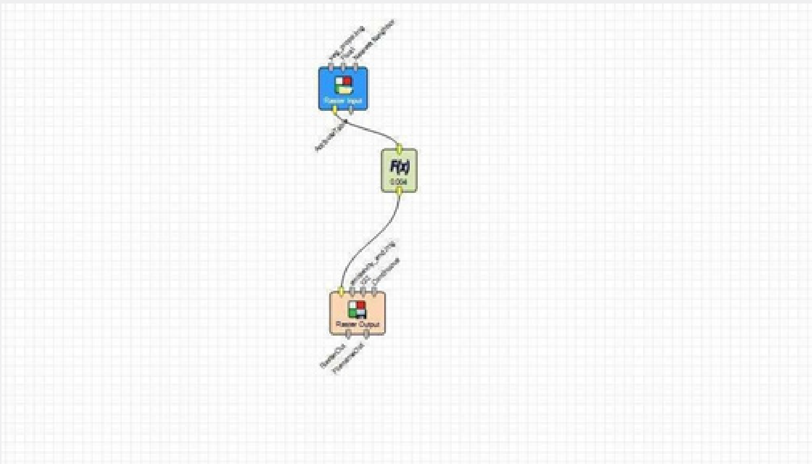

Figure 9: Model derived to calculate land surface temperature.

Calculation of land surface temperature (LST)

The land surface temperatures (LST) were computed as follows (Artis & Carnahan 1982) as cited in (Das 2015).

$$LST = \frac{BT}{\left\{1 + w * \left(\frac{BT}{p}\right) * Ln(e)\right\}}$$

Where BT= At satellite Temperature Brightness,

w= wavelength of emitted radiance (11.5 Am),

q = h*c/j (1.438_10_ 2m K),

j = Boltzmann constant (1.38*10-23J/K),

h = Planck's constant (6.626*10-34 J s), and c = velocity of light (2.998*108m/s).

e= Land Surface Emissivity.

(Figure 9 & 10)

F9 10

Validation of land surface temperature (LST)

This project was set to estimate land surface temperature (LST) using remote sensing technique and examine the distribution in temperature using environmental indexes. This was accomplished by surface temperature data retrieval from thermal infrared (TIR), Near Infrared (NIR) and red bands of Landsat 8 image with 169 path and 055 row. Retrieved land surface temperature from Landsat images was validated with ground meteorological data of three stations (Natri, Asendabo & Dedo) within the image which obtained from NMA/WOMSC (National Meteorological Agency/ Western Oromia Meteorological Service Center).

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The results of LST validation have been reported in quantitative form by computing the bias or deviation as Schneider et al. (2012) as cited in [6].

$$Bias = LSTsat - LSTref$$

whereas LSTsat- satellite-derived LST and LSTref - observation of a given reference LST, whichis assumed to be closer to the true value. According to Schneider et al. (2012) as cited in Agbor & Makinde [6] this convention ensures that a positive bias is indicative of an over estimate of the satellite LST, whereas a negative bias reflects a satellite LST that is too low with respect to the reference data set.

Methodological Flow Chart

(Figure 10)

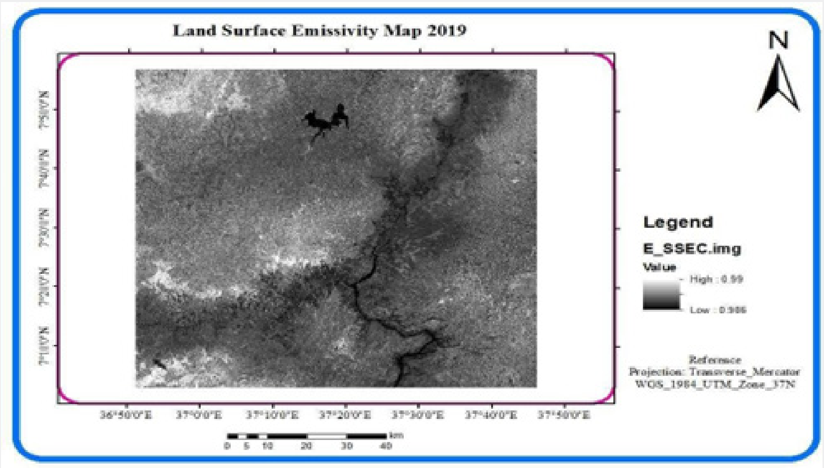

Figure 10: Land surface temperature emissivity map.c

Result and Discussion

From the result LST (Land Surface Temperature) final Image, we can see that the different changedistribution of LST from one region to another. In a red zone, it shows that the temperature in thatlocation is around 45 degrees, and the red color is rich in areas around and following the Gilgal Gibe and Main Gibe rivers and also its distribution is increase at the lower parts of the two rivers catchment with in the area.

An orange to yellow in color represent as the rural area, forest and agriculture, it is because thosesurfaces are capable of absorbing the heat coming from the sun through the plant and forest. Its LST ranges from 27 ^{0}C up to 36 ^{0}C. The area with blue (dark and bright) color in the LSTM indicates that the minimum LST is recorded in these areas. This area is covered with wetlands andwater bodies with LST from 19^{0}C up to 27 ^{0}C. this area is mainly located in the Gilgal gibe hydroelectric dam and Northwest, South and North east parts of the image. As for white and pinkin color, it's a cloud covering and the scene center time (the time at which the image is captured). From the metadata of the image from MTL file the cloud cover is about 0.51% and the time scenecenter is 07:46. The land usually with cloud cover is in cold temperature because it floating inthe air and the heat just passing through the cloud and does not absorbing any heat in it. This one of the factors to under and over estimation of land surface temperature (Figure 12 & 13).

The Land surface temperature validation is used the mean temperatures from three ground stationswithin the satellite image such as Natri, Asendabo and dedo and the actual temperature in the given corresponding pixels on the same day of the satellite passing over the area for three representative points. For the Landsat OLI data, the mean temperature of retrieved LST is 28.22**°C**and the mean near observed surface temperature is 27.51**°C**. The LST retrieving error is about +0.71**°C**. The observed temperature and satellite data were acquired the same day 23th of January,2019. The spatial consistency of Landsat temperature results with an error of about +0.71**°C** which indicated that remote sensing data is over estimation comparing with the station data [7].

Conclusion

This project paper presented a land surface Temperature (LST) mapping using its algorithms created in ERDAS Imagine 2015 and Arc GIS 10.3.1 for calculating the LST from Land sat 8 TIRS. The algorithm was derived using the observed thermal radiance of the TIRS Band 10 of Land sat 8 TIRS. To verify the final retrieved LST results, the near surface observed temperature from three stations with in the image was used. Data validation or accuracy assessment of results was conducted with available ground mean temperature information of this stations. Although theassessment revealed spatial consistency of Landsat temperature results in comparison with grounddata.

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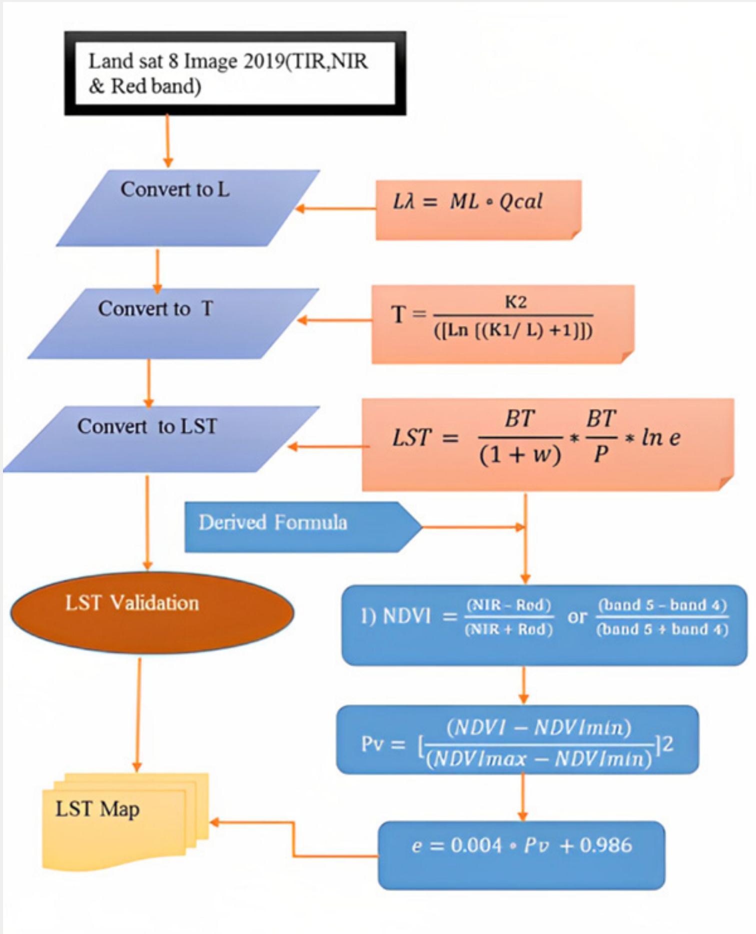

Figure 11: Methodological flow chart of the project.

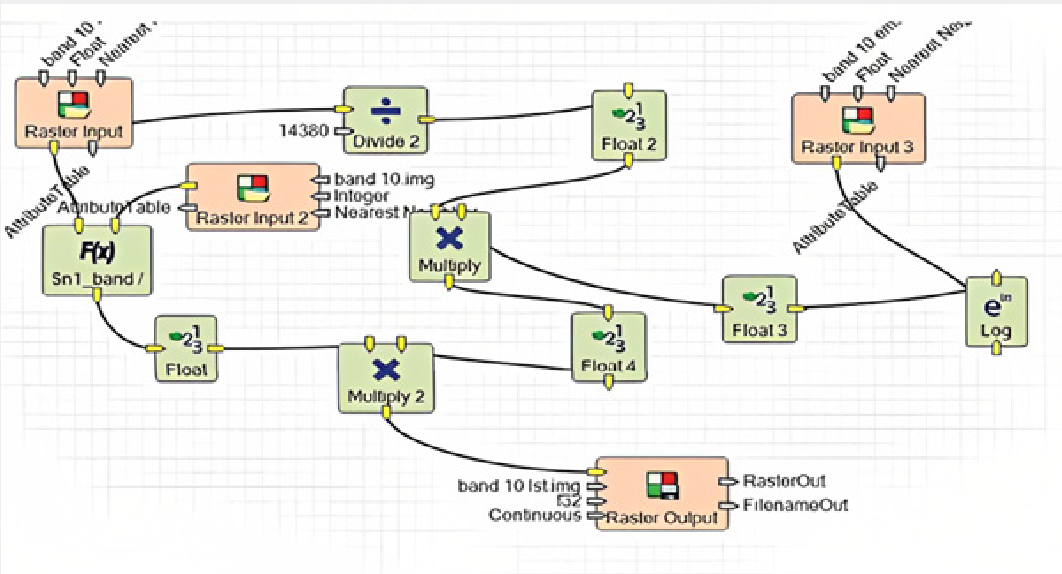

Figure 12: Model derived to calculate land surface temperature.

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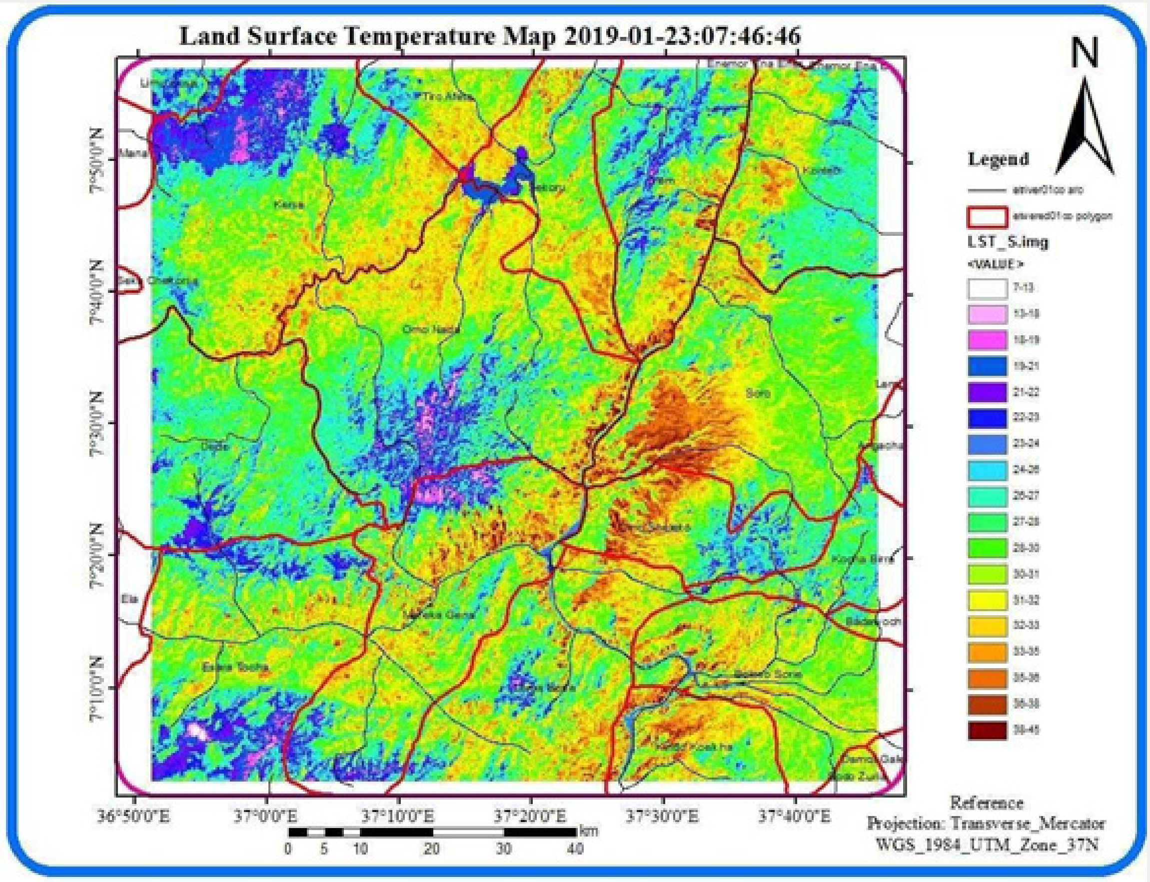

Figure 13: Final map of land surface temperature map.

There is change in LST distribution through land surface characteristics. Based on the final result of retrieved/derived land surface temperature the minimum and maximum LST is 7^0C and 45^0C with the mean LST of 28.22^0C. Through the retrieved temperature data, it was discovered that the distribution of maximum land surface temperature in the area is mainly located in the following Gilgal Gibe and main Gibe rivers and its lower part of catchment.

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