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Estimation of the ground surface temperature using Sebal method and the decision tree from ETM+ (Case study: Maraqeh Town)

Khalil Valizadeh Kamran *1

1University of Tabriz, Faculty of Planning and Environmental Sciences, Department of Remote sensing and GIS, Tabriz, Iran

Keywords
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Abstract

Land surface temperature is highly used in various kinds of studies, eg. Climatology, hydrology, Ecology, geology, design and improvement of the transport networks places. According to the stability of the land surface temperature in some limited number of climatology stations, and the need of the spatial surface temperature distribution in a vast area and simultaneously, the surface temperature was estimated. In order to access the surface temperature, the SEBAL (surface Balance Algorithms for Land) and the decision tree were used. The images used for SEBAL, were the ETM images taken on the 31st of August 2000, which were preprocessed by the Envi4.8 and ArcGIS9.3.In the study, the differences between the 12 years data of the surface temperature measured at the atmospheric stations (1993-2005), were compared with the data estimated by the SEBAL and there is in significant difference. So, the remote sensing can be recommended to be applied in the earth science and Environmental studies.

1. Introduction

Temperature of the surface of land, including Soil, Water, snow and plant covering, is one of the variables which is highly used in the earth science and environmental studies and a wide spatial view is usually needed, the RS technology, helps the studies of the variable be done in a vast area and temporal series of images, forms a continual spatial-temporal body of the variable. Such a continual body is used in the most modelling of the energy balance, like what is necessary in the evaporation estimation of an area, or optimization of the use and distribution of energy or the atmospheric pollutants (Danesh Kar & et al., 2004). According to the point measurements of the land surface temperature at a limited number of climatology stations, and the need of the spatial distribution of the surface temperature in a vast width at a same time, the temperature of the surface was estimated. Considering the advanced technology of the thermal RS, the Land Surface Temperature (LST) of a vast area, is obtained accurately. But the LST estimation is along with some error, because of being unknown the surface radiation (Runing, 1994).

In order to estimate the surface temperature of the land by the SEBAL algorithm, the ETM+ images taken the 31ft of August 2000 and the atmospheric data of the Maraqeh station of eastern Azerbaijan Province, were used.

The decision tree in the Envi4.8 and ArcGIS9.3 were used for preprocess and the algorithm of SEBAL process and the classification. The calibration and estimation of the land data were done by the SPSS 16 and Excel 2007. The levels of the task are shown in Figure 1.

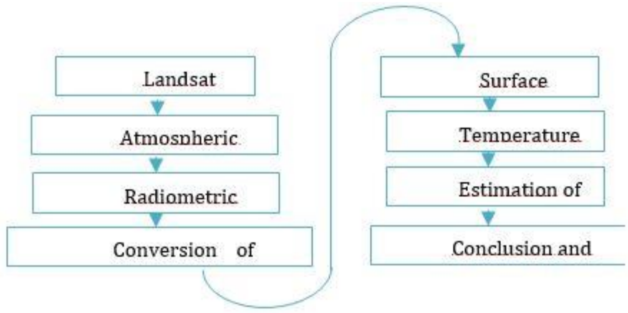

Figure 1. The chart of study process

2. Method

2.1. Study Area

The study area is located at 37 degree and 23 minutes of the north Latitude, and 46 degree and 16 minutes of the eastern longitude, on the southern side of

* Corresponding Author

*(e-mail) ORCID ID xxxx – xxxx – xxxx – xxxx

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Sahand Mountain. It reaches to the Uromia lake from west and Hashtroud from the east and to the Miandoab plain. The area of the city is 20 square kilometers. The climate is temperate and ranges between -20 to 35 ° C. the rainfall is 300 mm/year. The city is 135 kilometers far from Tabriz.

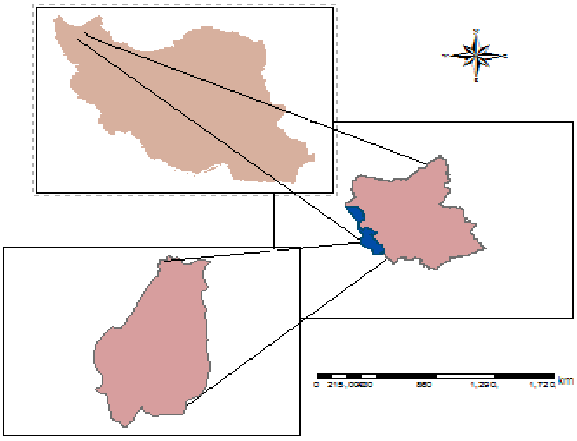

Figure 2. The study area

The SEBAL method, ETM+ images of 31st of August, was used to estimate the land surface temperature by the mono thermal band. The process was done as follows:

2.2. Preprocessing

The preprocessing includes the radiometric, atmospheric and geometric correction. The radiometric correction is the calculation of the spectral radiance. The atmospheric correction is the bulk correction of the reflection bands with the option of the dark subtract. The Envi4.7 and the thermal atm correction option were used to do the atmospheric correction.

- SEBAL method for calculation of the surface temperature:

The method estimates the surface temperature by the corrected thermal radiance (Allen et al., 2002). In order to calculate the corrected thermal radiance, the emissivity in the thermal band is needed. To calculate the thermal band emissivity needs the spectral radiance ($L\lambda$), reflectivity in each band (ρλ) and the surface Aledo, respectively.

- spectral radiance ($L\lambda$):

The spectral radiance is the radiance energy at the top of atmosphere which is detected by the sensors. The spectral radiance for each band is calculated by the following formula (Allen et al., 2002):

$$L\lambda = \frac{Lmax - Lmin}{255} * \mathbf{DN} + \mathbf{Lmin}$$

The DN is the grey degree of the pixels and the L max and L min are the calibration constants of the sensor and the $L\lambda$ is in (W /m2 / sr / µm). The L_{max} and L_{min} (Maximum and minimum of the spectral radiance in (W /m2 / sr / µm) detectable for each band by the sensor) for the ETM^+ sensor is brought in the Table 1.

Table 1. The L_{max} and L_{min} for ETM^+

Band	*Lmin*	*Lmax*
1	-6.200	293.700
2	-6.400	300.900
3	-5.000	234.400
4	-5.100	241.100
5	-1.000	47.570
61	0.000	17.040
7	-0.350	16.540
8	-4.700	243.100

In case of having the gain and offset values in the header file, the radiance can be estimated by the following formula (Landsat project science office, 2002)

$$L\lambda = gain * DN + offset$$

- Reflectivity of hemisphere (ρλ):

The surface reflectivity is the ratio of the reflected energy to the amount of energy striking the surface. The amount of the reflections is calculated in each band by the following formula (Allen et al, 2002)

$$\rho\lambda = \frac{\pi L\lambda}{\mathbf{ESUN\lambda} * \mathbf{cos\theta} * \mathbf{dr}}$$

The ρλ is the sperectal reflectivity for each band, ESUN λ is the average of the striking radiation of the sun at the top of the atmosphere for each band in (W /m2 / µm). The ESUN λ values for the ETM^+ sensor are shown in the table below (Allen et al, 2002).

Table 2. The ESUN λ values for the ETM^+

Band	6	5	4	3	2	1	7
ESUN λ	-	225.7	1044	1551	1840	1969	1368

Θ is the striking angle of the sun which is obtained as follows:

$$\theta = 90 - \beta$$

In which the β is the sun elevation which is obtained from Header file. In the study image, the sun elevation is 54.3277460.

d2 is the reverse of the square distance between the earth and the sun, which is calculated by the Beckman and Duffie formula (Allen et al,.2002).

$$dr = 1 + 0.033 \cos\left(DOY \frac{2\pi}{365}\right)$$

The DOY is the sequential day the amount of which is obtained according to the image date in the 243 paper (Ahmadian Marj, 2004)

- The surface albedo (α):

The Aledo is the ratio of the reflected electromagnetic radiation from the soil and plant surface to the striking radiation from the sun. The amount of the surface albedo is calculated by the following formula (Allen et al., 2002).

$$\alpha = \frac{\alpha toa - \alpha \mathbf{path} - \mathbf{radiance}}{\mathbf{\tau 2 sw}}$$

The αtoα is the top of the atmosphere albedo, αpath−radiance is the albedo caused by the effective radiance and the τ^2sw is the atmospheric transitivity. αpath−radiance is the average of some of the striking radiance which is transmitted by the atmosphere and shows the absorption and dispersion events happened in the atmosphere. Since the effect is available for the both striking and reflected radiance, the surface albedo is the square of the atmosphere transmission. τ sw , regarded a fair sky and dry weather, is obtained by the following formula:

$$\tau\ sw = 0.75+2*10^{-5}*z$$

In which the Z is the elevation from the sea in meter. The elevation should indicate the region elevation, like the climatology station elevation of the region (Allen et al., 2002). The station of Maraqeh is 147707 m.

αtoa is the top of the atmosphere albedo which is obtained by the formula below (Allen et al., 2002)

$$\alpha toa = \sum(\omega\lambda * \rho\lambda)$$

That ρλ spectral reflectivity for each band and ωλ is scaled coefficients for non-thermal bands. ωλ is calculated by the following function:

$$\omega\lambda = \frac{\text{ESUN}\,\lambda}{\sum \text{ESUN}\,\lambda}$$

For non-thermal bands of ETM^+, ωλ values is in the Table 3.

Table 3. The values of ω λ

Band	5	4	3	2	1	7
ω λ	0.028	0.131	0.194	0.23	0.246	0.171

Surface radiation is the ratio of the emitted thermal energy from surface to the emitted thermal energy from black body in same temperature .in SEBAL method two surface radiation is used. The first referred surface behavior for emitted thermal in thermal band that shown by εNB (10.4 to 12.5 micron). The second referred thermal wide range (6 to 14 micron) that shown by ε0. for calculate surface temperature (Ts), εNB is used. surface radiations is calculated by followed experimental functions:

When NDVI>0 we have:

a) For LAI<3

$$\varepsilon_{NB} = 0.97+0.0033*LAI$$
$$\varepsilon_0 = 0.95+0.01*LAI$$

b) For LAI>3

$$\varepsilon_{NB} = 0.98,\ \varepsilon_0=0.98$$

In water and snow for εNB and ε0 filter is used.

Water:
NDVI<0, α<0.47→ ε_{NB}=0.99, ε_0=0.985

Snow:
NDVI<0, α≥0.47 → ε_{NB}=0.99, ε_0= 0.985

In top function NDVI is The Normalized Difference Vegetation index, LAI is leaf surface index and α is surface albedo.

$$NDVI = \frac{B4 - B3}{B4 + B3}$$

LAI = 0.57.exp (2.33.NDVI)

LAI function is depending to production type and geographical position and manufactured on the basis of NDVI-LAI relation mean in Czech Republic of America (Tewari et al., 2003).

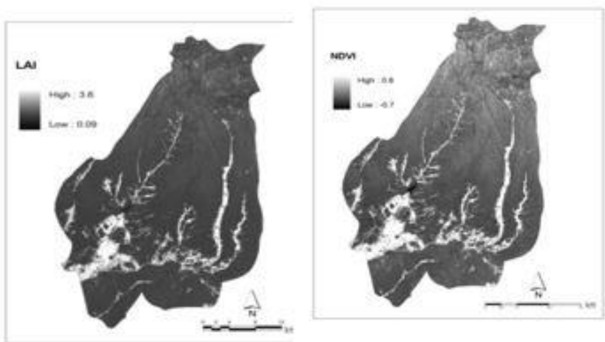

Figure 3. The map of NDVI and LAI of study area

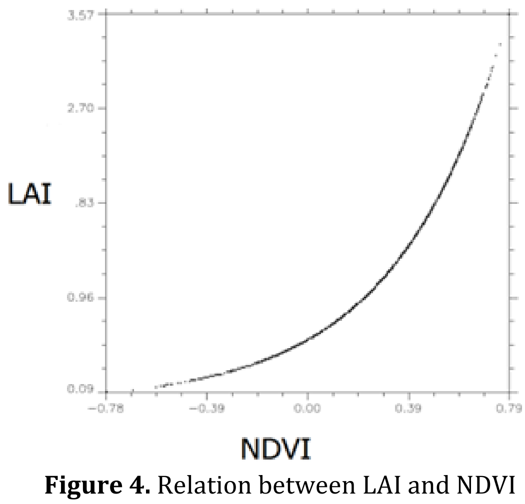

Figure 4. Relation between LAI and NDVI

Due to present of conditions and threshold levels for estimating surface radiation, decision tree method for classifying is used. With definition of threshold levels, desired bands, LAI, NDVI and (α), decision tree option from ENVI software environment is used to running function. The following classification can be seen in Figure 5.

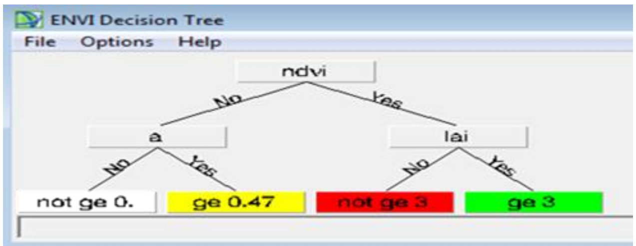

Figure 5. The decision tree in ENVI

Desired image from classifying convert to vector and then compiled to ArcGIS 9.3. After the process of dissolving, converting to raster and reclassifying, the value of each class saved in separated image as a Boolean function (Assigned value 1 to the class and zero to other). With importing these files to ENVI 4.7 surface radiation values calculated in each class. Finally with aggregating of three files, the value of surface radiation is assessed on total.

Corrected thermal radiance (Rc)

R_c is actual emitted radiance that is corrected for atmospheric effects. The following relation is offered by Wukeli & etal for correcting emitted thermal radiance (Allen et al., 2002).

$$Rc = \frac{LNB - RP}{\tau NB} - (1 - \varepsilon NB)Rsky$$

L_{NB} is radiance of thermal band, R_P is course radiance of thermal band, R_{sky} is radiance of clear sky in thermal band, and τ_{NB} is atmospheric transition capability in thermal band. R_{sky} can calculate by following experimental formula that offered by Idso-Jackson. T_a is air temperature near surface (k) in pass moment. τ_{NB} and R_P values respectively was placed 1 and 0. (Ahmadian, 2006). Due to unequal pixel size of thermal band and other band resize data option were used.

$$Rsky = (1.807 \times 10 - 10)Ta4[1 - 0.26 * \exp(-7.77 * 10 - 4[273.15 - Ta]2)]$$

T_a is air temperature near surface (k) in pass moment. τ_{NB} and R_P values respectively was placed 1 and 0. (Ahmadian, 2006). Due to unequal pixel size of thermal band and other band resize data option were used.

Surface temperature:

Using the following formula is calculated.

$$Ts = \frac{k2}{Ln(\frac{\varepsilon\ NB * K1}{Rc} + 1)}$$

Values of k1 and k2 are respectively 666.09 and 1282.71. All stages for calculating surface temperature except decision tree part was used Band Math option from Envi4.7. Final stages were done in Arc GIS 9.3.

3. Results

With respect to the lack of ground data of surface temperature on 10:09 am and need to estimate temperature in ...(10:09 am) single variable regression method were used. Using 12 years measured data from August in different hours (1993 to 2005), regression equation is prepared. For estimation of single-variable regression, Excel2007 and SPSS 16 was used.

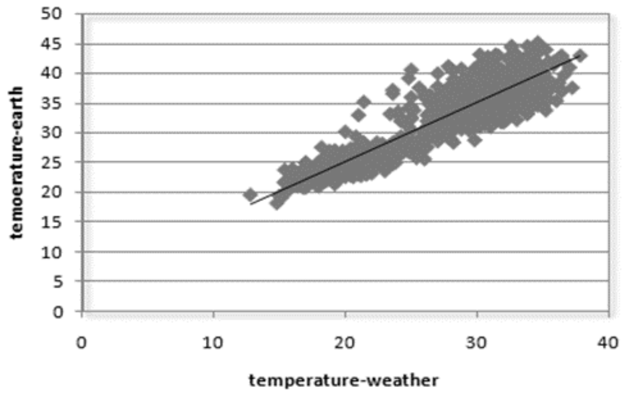

Figure 6. Diagram of estimated land data

Table 4. Computation of "R^2

R	R Square	Adjusted R Square	Std. Error of the Estimate
.914	.836	.836	2.43828

Table 5. Computation of F"

Model	Sum of Squares	df	Mean Square	F
Regression	36140.598	1	36140.598	6.079E3
Residual	7092.651	1193	5.945	
Total	43233.249	1194		

y = 0.994x + 5.159

In this equation x is air temperature and y are ground temperature at 5 cm depth. With knowledge of air temperature in 31 August 2000, ground temperature at the 5 cm depth in meteorological station of Maraqhe have estimated.

Obviously, the temperature difference between soil temperature at 5 cm depth and surface is variable during day. Research by Vazquez & et al., (1997) in the region of spain was that the temperature difference between surface and depth of soil is variable during the day. As in the early morning hours, the difference is negligible and then surface temperature increased than the temperature at 5 cm depth. From 12 to 14 pm surface temperature is about 10 degrees higher than the temperature at 5 cm depth. During sunset the temperatures of surface and depth are equal. At the night temperature in depth of soil will increase. As a result, at the desired time of this paper, surface temperature more than 5cm soil depth temperature and is less than 10 degrees centigrade. Due to the lack of exact amount of difference, temperature difference between estimated through remote sensing processing and 5cm depth of soil are considered. But we know the difference will be less.

Errors related to mismatch of thermal band resolution and other bands, geometric correction, atmospheric correction, lack of calibrated parameters in the study area, uncertainty of accuracy used meteorological data (Mobasheri & et. al., 2005) and the lack of measured data of ground surface at a desired time in meteorological stations. These are example of errors in the process of current research.

4. Conclusion

Estimation of ground surface temperature in several studies is required continuously. The following table can be said using SEBAL method, difference between actual and estimated surface temperature of satellite image less than 5.57 degree in meteorological station of maraqeh. If more accurate atmospheric data at time of imagine is available and more accurate atmospheric corrections, surface temperature estimation accuracy can be improved.

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