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Environmental Sustainability and Landscape Management

Editors

Recep Efe
İsa Cürebal
Abdalla Gad
Brigitta Tóth

St. Kliment Ohridski University Press, Sofia

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CONTENTS

Chapter 1	1
Landscape Architecture and Creating Innovative Spaces under Highway Overpasses	
Yasemin CINDIK AKINCI, Sara DEMIR, Oner DEMIREL	
Chapter 2	11
Visual Landscape Assessment of the Alpine Rocky Habitats: A Case Study of Hatila Valley National Park, Artvin, Turkey	
Derya SARI, Cengiz ACAR	
Chapter 3	35
Assessment of Children's Playgrounds in Terms of Design Approach, Physical Characteristics and User's Ideas	
Habibe ACAR	
Chapter 4	58
A Methodological Research on the Investigation of the Urban Landscapes Using Serial Vision Qualities: The Case of Trabzon City	
Arzu KALIN, Ali ÖZBİLEN, Sonay ÇEVİK	
Chapter 5	81
Sustainable Management and Protection of Historical Landscape: The Case of Bakırköy Mental and Psychiatric Diseases Hospital Garden, Istanbul - Turkey	
Hande Sanem CINAR ALTINCEKIC, Reyhan ERDOĞAN, Huseyin DIRİK, Ekin OKTAY	
Chapter 6	100
Urban Green Areas and Design Principles	
Serap YILMAZ, Sema MUMCU	
Chapter 7	119
Agricultural Landscape Values of Turkey	
Nilgün GÜNEROĞLU, Makbulenur BEKAR	
Chapter 8	138
The Effect of Plants on Indoor Air Quality	
Hakan SEVİK, Mehmet CETİN, Nur BELKAYALI, Kerim GÜNEY	
Chapter 9	150
Evaluation of Open Space Utilization Opportunities of University Campuses in the Aspect of Physical Disabled People: Case of Karadeniz Technical University Campus	
Ertan DÜZGÜNEŞ, Mehtap ERDOĞAN	
Chapter 10	169
Seating Furniture in Open Spaces and Their Contribution to the Social Life	
Sema MUMCU, Serap YILMAZ	

Chapter 11	188
Landscape Design Approaches Based on Fractal Geometry	
Filiz ÇELİK	
Chapter 12	205
Cultural Landscapes as Heritage: A Landscape-Based Approach to Conservation	
Ayşegül TANRIVERDI KAYA	
Chapter 13	222
Mycorrhiza and Its Role in Landscape Architecture	
Müberra PULATKAN	
Chapter 14	239
Evaluation of Spatial Permeability Concepts: A Case Study of the Trabzon Forum Shopping Centre	
Aysel YAVUZ, Nilgün KULOĞLU	
Chapter 15	257
Endemic Plants of Bursa and Their Landscape Characteristics	
Nilüfer SEYIDOĞLU AKDENİZ, Murat ZENCİRKİRAN	
Chapter 16	274
Explicating the Historical Landscape Approach According to Renovation Projects of Historical Environment in Turkey	
Aysun TUNA	
Chapter 17	291
Analysis Temporal Land Use/Land Cover Change Based on Landscape Pattern and Dynamic Metrics in Protected Mary Valley, Trabzon from 1987 to 2015	
Sara DEMİR, Öner DEMİREL	
Chapter 18	307
The Monumental Plane Trees of Bursa and Their Contribution to Cultural Landscape	
Murat ZENCİRKİRAN, Nilüfer SEYIDOĞLU AKDENİZ, Elvan ENDER, Zeynep PİRSELİMOĞLU BATMAN	
Chapter 19	320
Evaluation of Visual Effects of Roadways in Urban Areas: The Case Study of TAG Highway	
Deniz ÇOLAKKADIOĞLU, Muzaffer YÜCEL	
Chapter 20	335
Designing Landscape for Children's Development and Nature Conservation: Mutual Benefit	
Aysel USLU, Pelin KÖRMEÇLİ	
Chapter 21	351
Landscape Planning and Design in the Fight Against Obesity	
Sebahat AÇIKSÖZ, Deniz ÇELİK	

Chapter 22	366
Evaluation of Design and Liveability from a Critical Viewpoint in Çanakkale Waterfront Area	
Melda AÇMAZ ÖZDEN, A. Tolga ÖZDEN	
Chapter 23	382
Slow Cities as a Tool for the Sustainability of a Healthy Physical Environment	
Çiğdem KILIÇASLAN, Emine MALKOÇ TRUE	
Chapter 24	396
Land Art as a Contemporary Remark on Forming the Landscape	
Banu OZTURK KURTASLAN	
Chapter 25	411
Purposes of Waterscapes Usage in Landscape Architecture	
Tuğba DÜZENLİ, Doruk Görkem ÖZKAN	
Chapter 26	425
A New Approach of Landscape Planning for Turkey: Historical Landscape Character Assessment	
Sara DEMİR	
Chapter 27	439
The Significance of Ecological Approaches in Local Governance Systems	
Duygu AKYOL, İpek ÖZBEK SÖNMEZ	
Chapter 28	453
The Techniques Improving the Creativity in Landscape Design Process	
Banu Çiçek KURDOĞLU, Burcu SALİHOĞLU, Kadir Tolga ÇELİK	
Chapter 29	467
Utilization of Living Walls in Urban Ecosystems	
Makbulenur BEKAR, Nilgün GÜNEROĞLU	
Chapter 30	483
Applying Landscape Ecology Principles in Urban Landscape Design for Improving Biodiversity	
Aysel USLU, Nasim SHAKOURI	
Chapter 31	496
A Research on Accessibility of Urban Parks by Disabled Person: The Case Study of Birlik Park, Konya-Turkey	
Sertaç GÜNGÖR	
Chapter 32	512
Ecological Approach to Rural Development	
Pınar BOLLUKCU, Sebahat AÇIKSÖZ	

Chapter 33	523
Brussels' Urban Cultural Landscapes: New Design Concepts by International Students	
Veli ORTAÇEŞME, Meryem ATIK, Tahsin YILMAZ, Steven GOOSSENS, Pol GHEKIERE, Oğuz YILMAZ, Aysel USLU, Cornelius SCHERZER, Wolfgang FISCHER	
Chapter 34	535
The Importance of Spatial Ability Research: The Case of Landscape Architecture Education	
Ahmet AKINCI, Yasemin CINDIK AKINCI	
Chapter 35	545
Contribution of Green Infrastructure System on Water Management	
Aybike Ayfer KARADAĞ, Demet DEMİROĞLU	
Chapter 36	560
LST Calculator: A Python Tool for Retrieving Land Surface Temperature from Landsat 8 Imagery	
Hakan OĞUZ	
Chapter 37	573
Determining the Recreational Potentials of Some of the Bays in Fethiye	
Zeynep R. BOZHÜYÜK ARDAHANLIOĞLU, Nihat KARAKUŞ	
Chapter 38	585
Investigation of Active Green Spaces within the Criterion of Earthquake Park Concept: Case Study of Safranbolu City	
Yasin DÖNMEZ	
Chapter 39	592
Utilization of Natural Materials as Mulching Materials in Landscaping Applications	
Şirin DÖNMEZ, Mert ÇAKIR	
Chapter 40	598
Automated Land Surface Temperature Retrieval from Landsat 8 Satellite Imagery: A Case Study of Kahramanmaraş - Turkey	
Hakan OĞUZ	
Chapter 41	605
Identifying Land Use/Land Cover Dynamics in the Ahir Mountain, Kahramanmaraş, Using Multi-Temporal and Multi-Scale Satellite Imagery	
Nurdan ERDOĞAN, Hakan DOYGUN	
Chapter 42	616
Landscape Preferences of the Elderly	
Emine TARAKÇI EREN	
Chapter 43	626
Recreational Requirements of Adolescents on Parks in Ankara, Turkey	
Rukiye Duygu ÇAY, Dicle OĞUZ	

Chapter 44	636
Evaluation of Landscape Architecture Students' Awareness of Their Career	
Zöhre POLAT	
Chapter 45	646
Urban Design	
Murat ÖZYAVUZ	
Chapter 46	655
Stormwater Management in the Context of Sustainable Drainage Concept in Urban Areas	
Elif BAYRAMOĞLU, Öner DEMİREL	
Chapter 47	665
The Influence of Natural Flora on Landscaping: The Case of Uçmakdere (Tekirdag)	
Burcin EKICI	
Chapter 48	675
Topography, Hybridization and Deconstructivism Effects on New Typologies in Landscape Design	
Elvan ENDER, Aysun ÇELİK, Nilüfer SEYİDOĞLU AKDENİZ	
Chapter 49	684
Relations Between Precipitation and Forest Distribution in Turkey	
Atilla ATİK	
Chapter 50	694
Assessment of the Relationships Between Urban Furniture and Urban Spaces	
Elif SATIROĞLU	
Chapter 51	703
Sustainable Landscape Design in Contemporary Residential Gardens	
Fatma AŞILIOĞLU	
Chapter 52	721
Assessment of Psycho- Social Effect of Interior Components on User Perception In Terms of Historical Buildings	
Çiğdem ÇETİNKAYA	
Chapter 53	728
Livability and Livable City Image	
Banu Çiçek KURDOĞLU, Pınar DİNÇER	
Chapter 54	735
Design Principles of Earthquake Park	
Aysun ÇELİK, Elvan ENDER	

Chapter 36

LST Calculator: A Python Tool for Retrieving Land Surface Temperature from Landsat 8 Imagery

Hakan OĞUZ*

INTRODUCTION

Land surface temperature (LST) is a key parameter which plays an important role in many environmental studies (Xiao *et al.*, 2007). Urban heat island effect, global warming, enhanced green-house effects and other environmental problems have become crucial subjects to overcome in the last decades. LST retrieval using remotely sensed data is currently one of the most popular subjects in environmental studies during the last couple of decades with Landsat data.

Several algorithms have been developed by researchers to calculate LST but the most used ones are Split-Window (SW) algorithm, Single-Channel (SC) algorithm, and Radiative Transfer Equation (RTE) (Abrams, 2000; Cristóbal, Jiménez-Muñoz, Sobrino, Ninzerola, & Pons, 2009; Jimenez-Munoz, Sobrino, Skokovic, Mattar, & Cristobal, 2014; Jimenez-Munoz & Sobrino, 2003; Oguz, 2013; Oguz, 2015; Yu, Guo, & Wu, 2014; Sobrino *et al.*, 2007).

In this study, the radiative transfer equation-based method was employed due to the fact that it is easy to implement and it was also found to have the highest accuracy compared to SW and SC algorithms (Yu *et al.*, 2014). Landsat 8 data contains 11 bands ranging from 15m panchromatic to 100m thermal bands. Landsat 8 bands 4 (Red), 5 (NIR), and 10 (TIR-1) are the only bands required by the toolbox to calculate LST.

MATERIALS AND METHODS

Landsat 8 TIRS Bands

Landsat 8 satellite was launched in February 2013 for the continuity of remote sensing data at high spatial resolution in the Landsat Data Continuity Mission. Landsat 8 carries two instruments: The operational Land Imager (OLI) sensor along with multispectral bands 1-7 and 9 with 30 meters (except for band 8 which is panchromatic with 15m resolution) and the Thermal Infrared Sensor (TIRS) which collects data at a 100m spatial resolution with two bands (bands 10 and 11). Landsat 8 products are delivered as 16-bit images which enable better characterization of land cover state and condition.

The new TIRS have an advancement over the previous TM/ETM sensors by having two TIR bands in the atmospheric window between 10 and 12 μm (Jimenez-Munoz *et al.*, 2014). As illustrated in Figure 1 below, the previous single band has been split into two TIR bands which are now narrower than the previous TM/ETM TIR band. Further information regarding the sensor is presented in Table 1.

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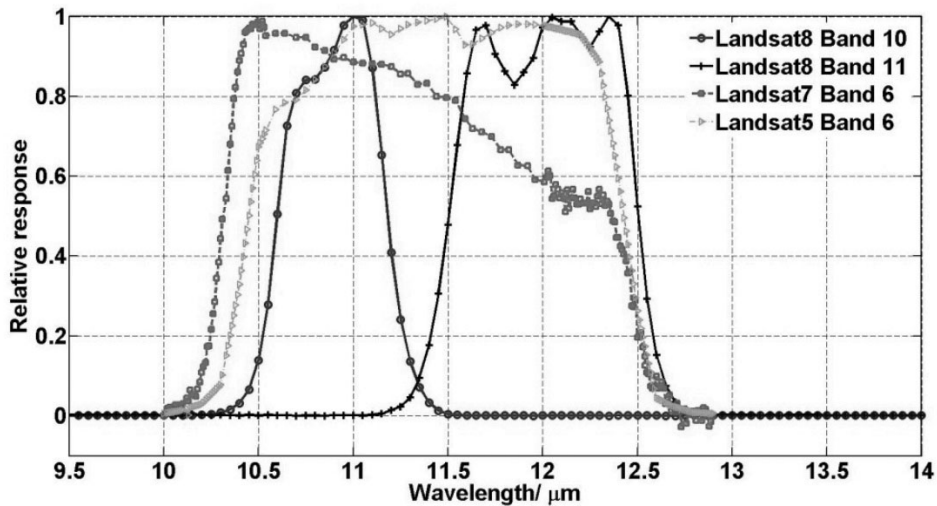


Figure 1: Spectral Response for thermal bands of different sensors (Source: Yu *et al.*, 2014)

Table 1: Characteristics of the Landsat 8 Data

Band No	Band Name	Band Width(μm)	Spatial Resolution (m)
Band 1	Coastal/Aerosol	0.435 - 0.451	30
Band 2	Blue	0.452 - 0.512	30
Band 3	Green	0.533 - 0.590	30
Band 4	Red	0.636 - 0.673	30
Band 5	NIR	0.851 - 0.879	30
Band 6	SWIR-1	1.566 - 1.651	30
Band 7	SWIR-2	2.107 - 2.294	30
Band 8	Pan	0.503 - 0.676	15
Band 9	Cirrus	1.363 - 1.384	30
Band 10	TIR-1	10.60 - 11.19	100
Band 11	TIR-2	11.50 - 12.51	100

(Source: Landsat 8 Data Users Handbook, 2016)

The Radiative Transfer Equation (RTE) Algorithm

The RTE algorithm retrieves LST (T_s) using the equation (1):

$$T_s = \left[\frac{c_2}{\lambda \ln \left\{ \frac{c_1}{\lambda^5 \left[\frac{L_{sen} - L_u - \tau(1 - \varepsilon)L_d}{\tau \varepsilon} \right]} + 1 \right\}} \right] \quad (1)$$

where T_s is the land surface temperature, ε is the land surface emissivity, L_u is the upwelling atmospheric radiance, L_d is the downwelling atmospheric radiance, τ is the atmospheric transmissivity, λ is the effective band wavelength, $c_1 = 1.19104 \times 10^8 \text{ W} \mu\text{m}^4 \text{m}^{-2} \text{sr}^{-1}$ and $c_2 = 14387.7 \mu\text{m K}$ are the constants. L_{sen} is the thermal radiance at-sensor level and calculated by as follows:

$$L_{sen} = [\varepsilon B_{TS} + (1 - \varepsilon)L_d]\tau + L_u \quad (2)$$

where B_{TS} is the spectral radiance ($\text{W}/(\text{m}^2 \text{sr} \mu\text{m})$).

The RTE method was selected and used in this particular study due to the fact that not only the model requires minimal and more accessible input data but also the procedure was found to be the least bias compare to other methods according to Yu *et al.*, (2014).

NDVI retrieval

Normalized difference vegetation index (NDVI) is a simple numerical index to assess the presence of live green vegetation. For Landsat 8 imagery, NDVI is computed using band 4 (RED) and band 5 (NIR) with the following Eq. 3:

$$NDVI = \frac{\rho_{band5} - \rho_{band4}}{\rho_{band5} + \rho_{band4}} \quad (3)$$

where ρ_{band5} stands for the spectral reflectance measurements acquired in the NIR band and ρ_{band4} represents the spectral reflectance measurements acquired in the RED band.

Afterwards, this NDVI file is used as an input to calculate Fractional Vegetation Cover (FVC) values as shown in Eq. 4 below (Skokovic *et al.*, 2014):

$$FVC = \frac{NDVI - NDVI_s}{NDVI_v - NDVI_s} \quad (4)$$

where $NDVI_v$ and $NDVI_s$ stand for NDVI values of full vegetation cover and bare soil respectively.

Emissivity retrieval

Emissivity is described as a proportionality factor, which scales black body radiance by Jimenez-Munoz, Sobrino, Gillespie, Sabol, & Gustafson (2006) to estimate emitted radiance. Therefore, emissivity is a vital role for the accuracy of land surface temperature retrieval. Several approaches have been proposed over the past decades to retrieve land surface emissivity from NDVI (Jimenez-Munoz *et al.*, 2006; Sobrino & Raissouni, 2000; Valor & Caselles, 1996; Van de Griend & Owe, 1993). In this study, Sobrino *et al.*'s (2008) land surface emissivity retrieval approach has been adopted (Eq. 5):

$$\text{If } FVC = 0 \quad \rightarrow \quad \varepsilon = 0.979 - 0.046 * \rho_{band4} \quad (5a)$$

$$\text{If } 0 < FVC < 1 \quad \rightarrow \quad \varepsilon = 0.971(1 - FVC) + 0.987 * FVC \quad (5b)$$

$$\text{If } FVC = 1 \quad \rightarrow \quad \varepsilon = 0.99 \quad (5c)$$

where FVC stands for Fractional Vegetation Cover, ϵ stands for land surface emissivity, and ρ_{band4} represents spectral reflectance for the RED band (band 4) of Landsat 8.

Any of the two thermal bands of Landsat 8 can be used in this study but Jimenez-Munoz et al. (2014) recommends Landsat 8 band 10 (TIR-1) due to its high atmospheric transmissivity. Therefore, band 10 has been employed in this study for the LST retrieval.

RESULTS

A Python Tool: LST Calculator

This program was developed using Python programming language (Python 2.7) and it can be run within ArcGIS Desktop, ESRI's complete GIS mapping platform. A request to get the tool can be made by contacting the author through his personal webpage at <https://hakanoguz.wordpress.com>. This toolbox consists of seven individual tools as illustrated in Figure 2 below: 1- TOA Radiance, 2- TOA Reflectance, 3- NDVI, 4- FVC, 5- Emissivity, 6- Lsen and 7- LST. The general flow diagram of the tool is given in Figure 3.

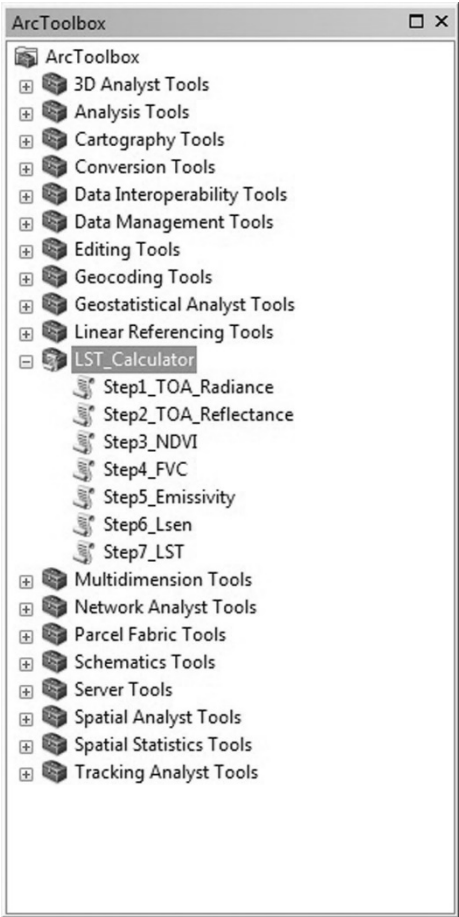


Figure 2: The main interface of the LST Calculator tool in ESRI ArcToolbox

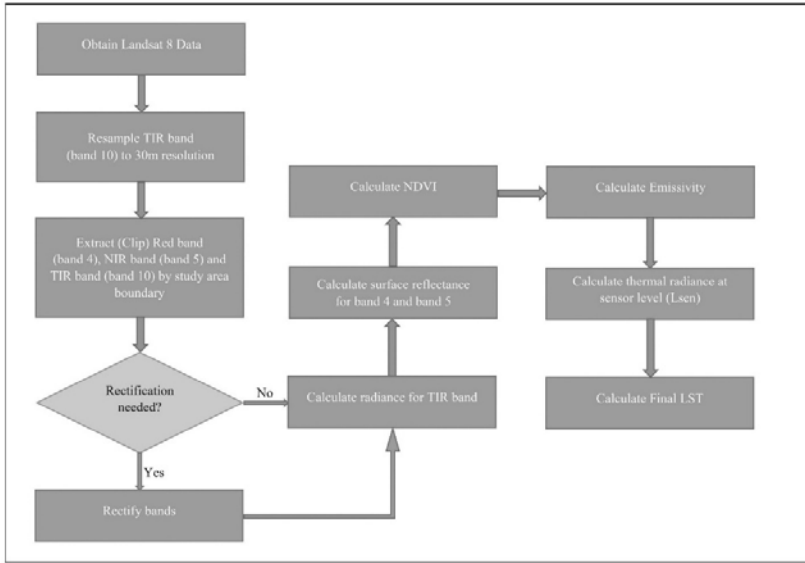


Figure 3: The flow diagram of the LST Calculator toolbox

TOA Radiance

At sensor Radiances for Landsat 8 bands are computed from following Eq. 6 (LDUH, 2016):

$$L_{\lambda} = (M_L * Q_{cal}) + A_L \quad (6)$$

where L_{λ} is spectral radiance ($W/(M^2 * sr * \mu m)$), M_L represents radiance multiplicative scaling factor for the band, A_L is the radiance additive scaling factor for the band, and Q_{cal} is pixel value in DN. These values are obtained from the metadata. Furthermore, Figure 4 illustrates the radiance calculation interface of the software tool.

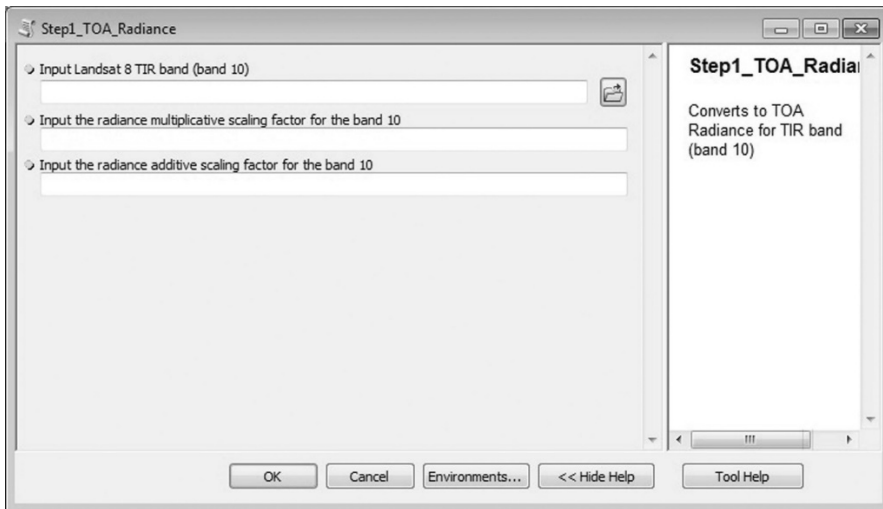


Figure 4: Radiance calculation interface for the TIR band

TOA Reflectance

After calculating at sensor radiances, planetary reflectances for the Landsat 8 RED and NIR bands (band 4 and band 5 only) are computed using the Eq. 7 (LDUH, 2016):

$$\rho_{\lambda} = \frac{M_p * Q_{cal} + A_p}{\sin(\theta)} \tag{7}$$

where ρ_{λ} is unitless TOA planetary reflectance, M_p is reflectance multiplicative scaling factor for the band, Q_{cal} is pixel value in DN, A_p is reflectance additive scaling factor for the band, and θ is solar elevation angle.

Figure 5 below shows the planetary reflectance calculation interface of the program. This step requires four parameters: Landsat 8 RED or NIR band, reflectance multiplicative scaling factor, reflectance additive scaling factor, and solar elevation angle,

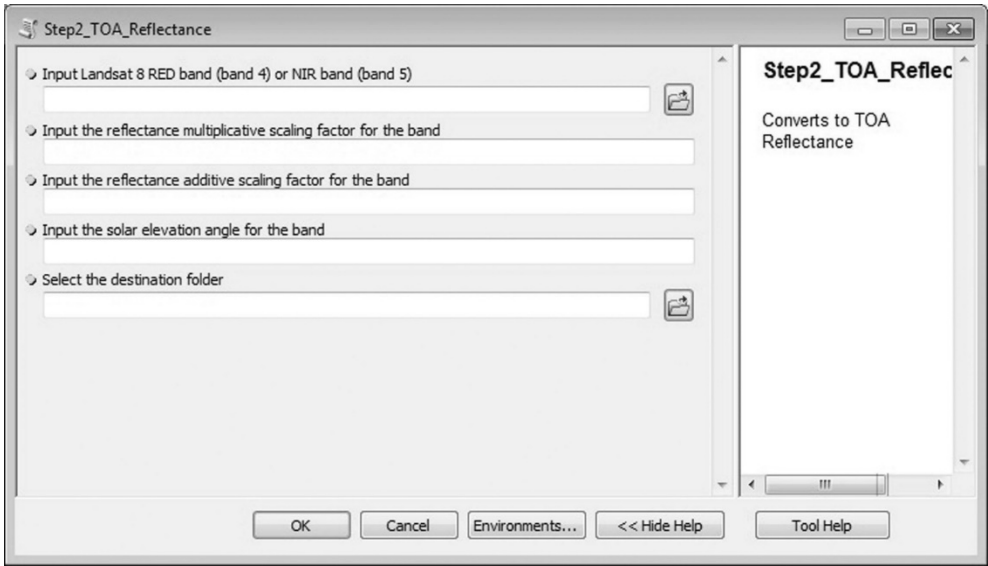


Figure 5: Reflectance calculation interface

NDVI interface of the tool is illustrated in Figure 6 below. This step requires RED band reflectance file and NIR band reflectance file only.

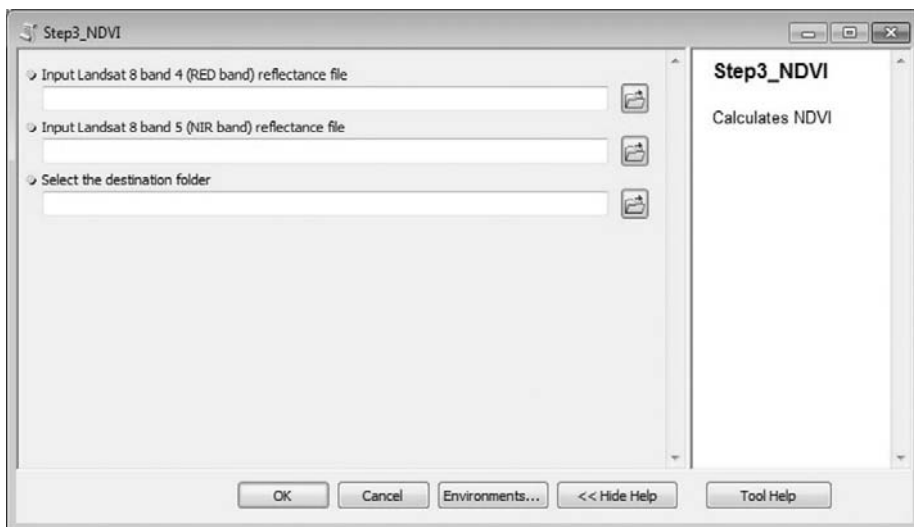


Figure 6: NDVI calculation interface

The FVC calculation interface is shown in Figure 7 below. In this step, the only band required is NDVI file.

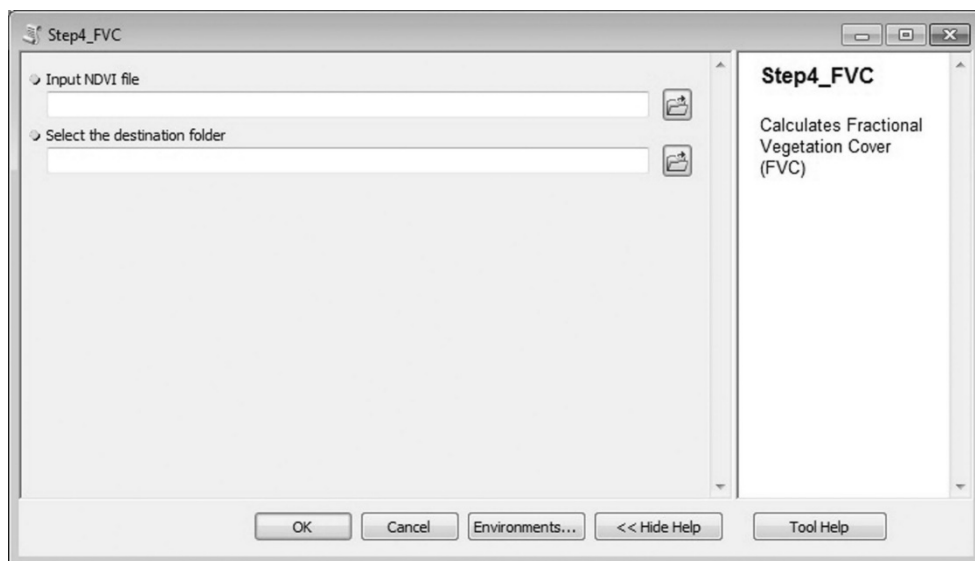


Figure 7: FVC calculation interface

The emissivity calculation interface is illustrated in Figure 8 below. This step requires only two parameters: 1- FVC file, and 2- Band 4 reflectance file.

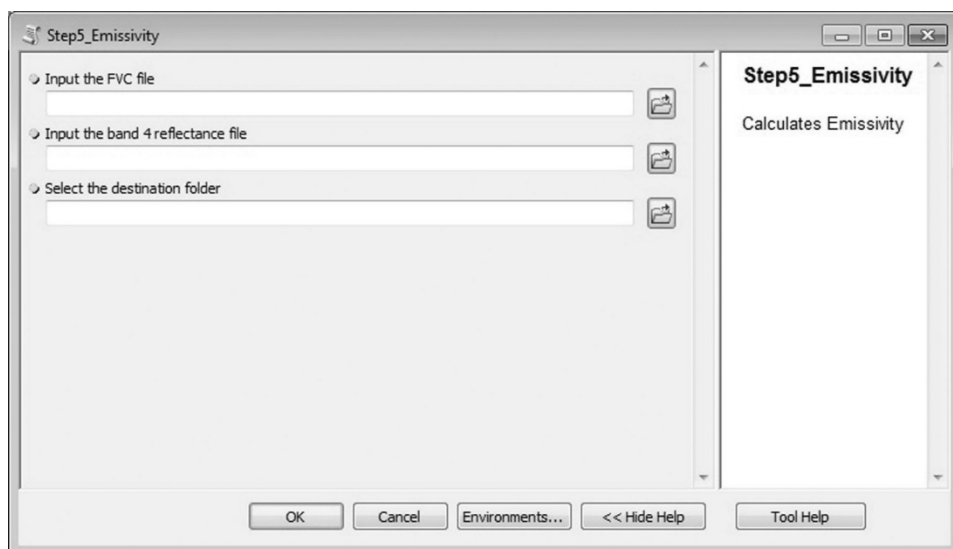


Figure 8: Emissivity calculation interface

The thermal radiance at sensor level (L_{sen}) calculation step requires five parameters: emissivity file, band 10 radiance file, down-welling atmospheric value, atmospheric transmission value, and up-welling atmospheric value, which can be obtained from Atmospheric Correction Parameter Calculator (ACPC) webpage (ACPC, 2016). The interface is shown in Figure 9 below.

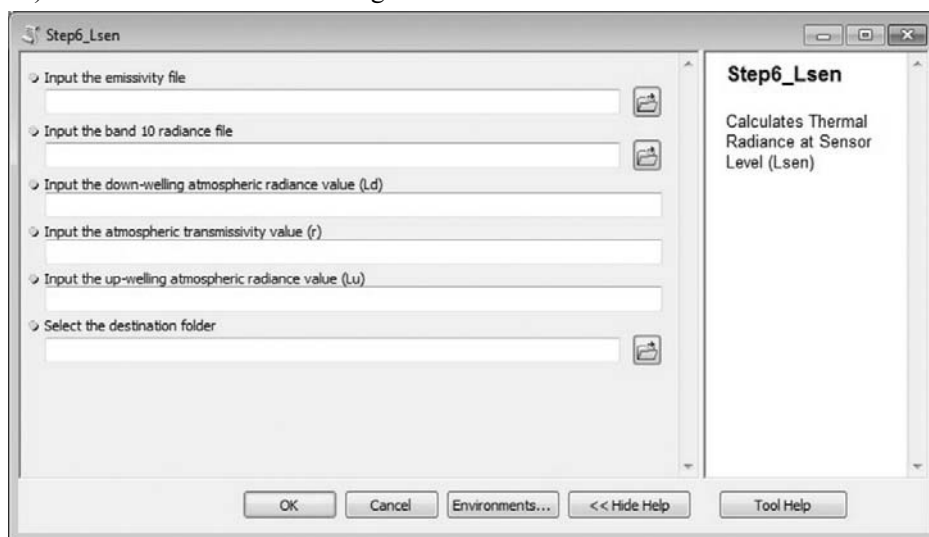


Figure 9: Thermal radiance at sensor level (L_{sen}) calculation interface

The final LST calculation interface requires emissivity file, the thermal radiance at sensor level file (L_{sen}), down-welling atmospheric radiance value, atmospheric transmission value, and up-welling atmospheric radiance value. The final LST calculation interface is seen in Figure 10 below.

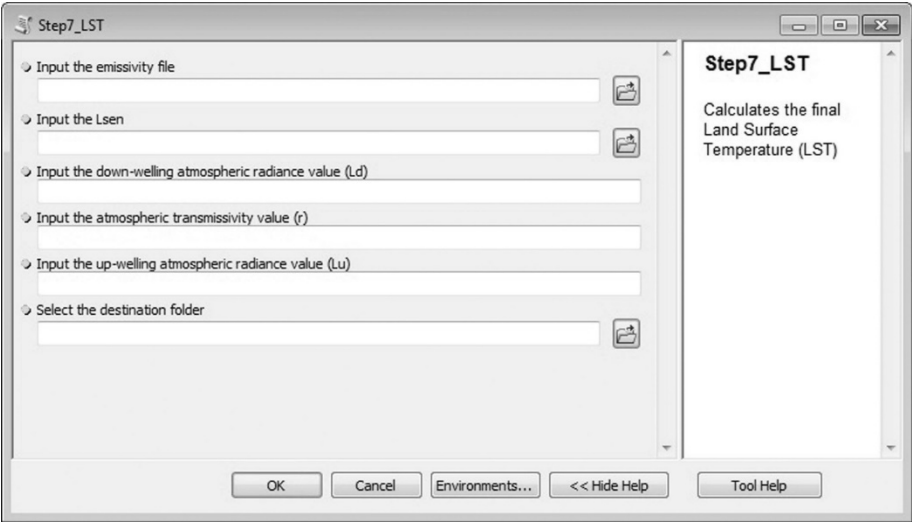


Figure 10: The final LST retrieval interface

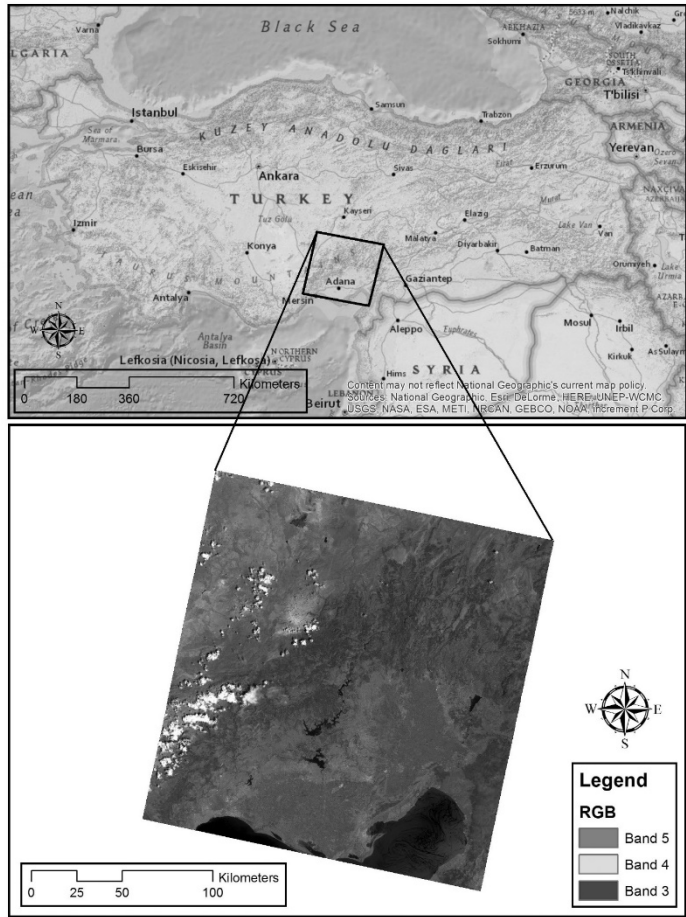


Figure 11: The sample Landsat 8 scene used in the demonstration

Software Demonstration

In order to demonstrate the LST Calculator toolbox, Adana, the fifth-largest city in Turkey has been selected as the study area as shown in Figure 11 above. Adana has witnessed a rapid development to become a metropolitan area and lies in the hearth of Cukurova which covers the cities of Adana, Mersin, Osmaniye, and Hatay. The region contains large flat fertile land that is regarded as one of the most productive areas of the world.

A Landsat 8 scene (path/row: 175/34), acquired on June 28 2014, was downloaded from Global Land Cover Facility website (GLCF, 2016). All the bands downloaded were resampled to 30m at GLCF except for panchromatic band that was distributed with 15m spatial resolution. The sample files and parameters used for demonstration are listed in Table 2 and Table 3 below.

Table 2: The sample files employed to calculate LST

File Name	Data Type	File Dimension (Row x Column)	Description
Band 4	TIF File	7591 x 7741	Landsat 8 RED Band
Band 5	TIF File	7591 x 7741	Landsat 8 NIR Band
Band 10	TIF File	7591 x 7741	Landsat 8 TIR Band

Table 3: The parameters used for the sample files

Parameter Name	Value
Atmospheric Transmissivity	0.79
Up-welling Atmospheric Radiance	1.80
Down-welling Atmospheric Radiance	3.01
Radiance multiplicative scaling factor for band 10	3.342×10^{-4}
Radiance additive scaling factor for band 10	0.1
Reflectance multiplicative scaling factor for band 4	2.0×10^{-5}
Reflectance additive scaling factor for band 4	-0.1
Reflectance multiplicative scaling factor for band 5	2.0×10^{-5}
Reflectance additive scaling factor for band 5	-0.1

The final spatial distribution of LST map was illustrated in Figure 12. The minimum and maximum temperatures of the scene were computed as -130 °C and 38 °C. As predicted, high temperatures were retrieved within dense urban areas (ranging from 31 to 38 °C) while extremely cold temperatures were calculated for the cloud cover (from -130 to -3 °C). If we exclude cloud cover, the lowest temperatures belong to water area ranging from 3.5 to 18 °C, and forested areas have temperatures ranging from 23 to 30 °C as shown in Figure 12 below.

DISCUSSION AND CONCLUSIONS

In this study, a Python toolbox was developed to retrieve land surface temperature from Landsat 8 imagery. This software can be an invaluable tool for those who are interested in thermal environment of earth's surface. This tool employs Radiative Transfer Equation algorithm for Landsat 8 and detailed information regarding the algorithm can be found in Skokovic *et al.*'s (2014) and Sobrino *et al.*'s (2008).

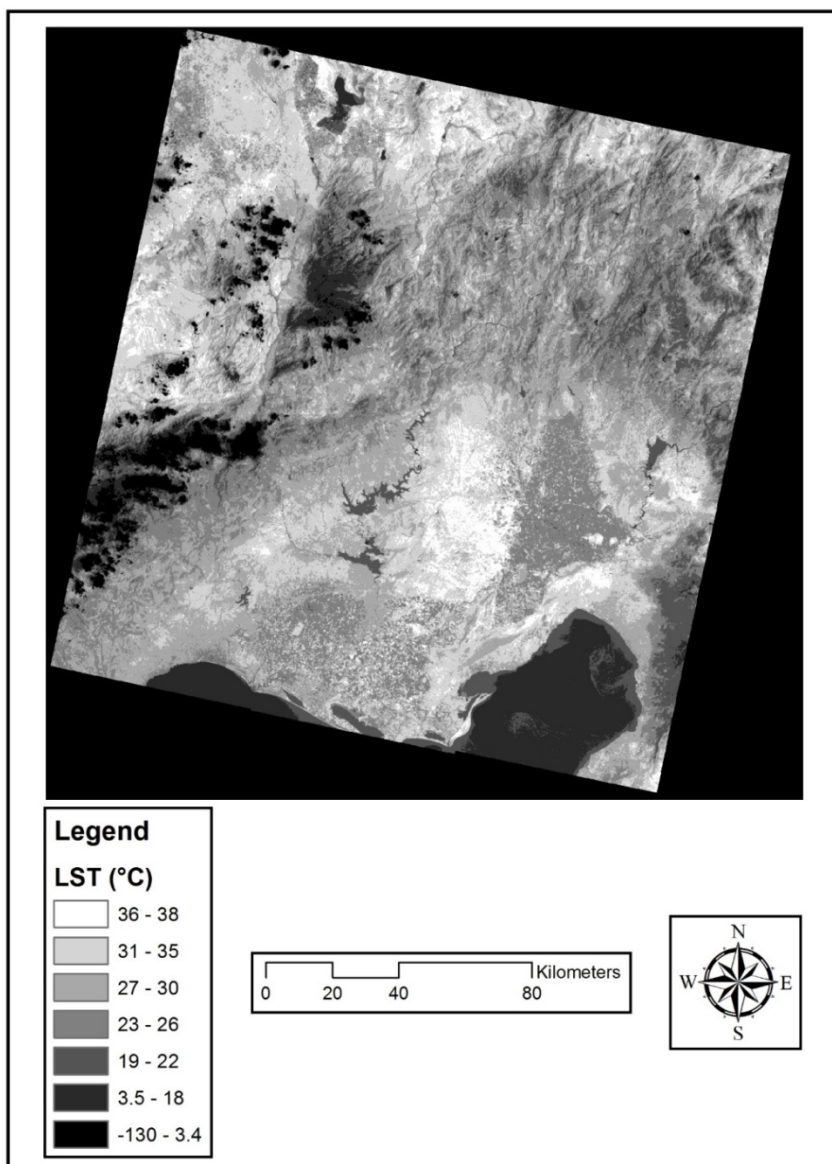


Figure 12: The spatial distribution pattern of land surface temperature

Furthermore, some atmospheric parameters are required prior to the calculation such as atmospheric transmissivity, up-welling and down-welling atmospheric radiances, which are essential to the retrieval of LST. These atmospheric parameters can be obtained from ACPC webpage (ACPC, 2016).

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