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THE IMPACT OF THE GREEN SPACES ON THE LAND SURFACE TEMPERATURE IN URBAN AREAS - ANALYSIS OF THE LAND SURFACE TEMPERATURE IN THE CITY OF ORADEA USING LANDSAT 8 SATELLITE IMAGES

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Abstract: *People living in urban areas face temperature discomfort due to the urban heat island phenomenon that is in correlation with the land surface temperature (LST) generated by the buildings for living and other construction. In this paper, we aim to use remote sensing data to retrieve the LST values to demonstrate the visual correlation that exists between these values and green spaces. To retrieve the LST values and to obtain the raster dataset necessary to identify the correlation between the green spaces and these values, we applied the method of single window algorithm using data from Landsat 8, acquired on 27th May 2021, in ArcGIS software for the City of Oradea area. The obtained results confirmed the strong correlation between green spaces and low values of land surface temperature.*

Key words: *LST, remote sensing, green spaces, single thermal band, TIRS.*

1. 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. LST is the temperature emitted by the surface and measured in kelvin [4]. Rising land surface temperatures affect glaciers, ice sheets, permafrost, and the vegetation in Earth's ecosystems. Increases in land surface temperature also have serious health implications for humans [8]. Land surface temperature not only does have serious health implications for humans, thinking at the global scale, but even in small urban areas, this temperature can create considerable discomfort for humans.

In urban areas, the quality of life is important and the responsibility for the environment lies with the inhabitants. The lack of proper urban planning, translated into the lack of constructions with low albedo material and de-vegetation in urban areas, causing those areas to have high LST than surrounding areas [12]. As an urban heat island (UHI) is a region

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with high LST than the surrounding areas, and knowing that the urban heat island effect can cause huge discomfort in human condition living, by identifying the regions from the city with the high LST values can help the actors in charge to conduct a better urban planning.

Satellite remote sensing data is used to determine how the temperature is distributed across de globe and Landsat is the longest satellite mission who provides the data necessary to study it [3]. At the moment the study has been conducted the Landsat 8 was the newest satellite in operation from the Landsat mission.

Referring to the European Organization for the Exploitation of Meteorological Satellites (EUMESAT) training portal we identify two directions to follow in order to solve the radiative transfer equation (RTE) which conducts to obtain the LST values.

The first category starts from the premise that we know a priori the land surface emissivities and consists of the following methods: single window method, multi-channel method, and multi - angle method.

The second category assumes that the land surface emissivity is not known and implies the following methods: stepwise retrieval method, simultaneous retrieval of land surface emissivity and LST with known atmospheric information, and simultaneous retrieval with unknown atmospheric information [10].

Based on all the data we had for conducting this study we presume that the single window method algorithm and the City of Oradea area, through the proportion of the green spaces and the distribution of them, will meet our expectations to retrieve the LST values in order to demonstrate the visual correlation that exists between these values and green spaces.

2. Materials and Methods

2.1. Study Area

In order to prove that the satellite data can be used to retrieve the LST values through ArcGIS software and that these values are in strong correlation with the green spaces, we focused our study on the City of Oradea area, the Municipality of Bihor County presented in Figure 1. The City of Oradea is located in the north-western part of Romania, on the two banks of the river Crisul Repede, just 10 km from the state border with Hungary, with geographical coordinates 21^{o}56’25’’ longitude and 47^{o}03’05’’ north latitude (WGS84). Considering that The City of Oradea is located at the contact of the Western Plain with the Western Hills, it folds on the geological structure that defines it. As relief units, we mention the western part of The Crisurilor Plain which has as subunits The Barcau - Biharia Plain developed at the contact between The Crisurilor Plain and The Hills of Oradea [6].

The City of Oradea has a moderate temperate climate with western influences, with an average annual temperature of 10.5 ^{o}C with non-periodic variations. The average annual rainfall in the city is 615.8 mm [6].

According to the National Institute of Statistics in Oradea in January 2020 lived a number of 221413 people and according to the records of Oradea City Hall, the housing stock of the city is about 66500 apartments and 20.000 houses. Following the census of the green spaces that the municipality has conducted in 2021 it was found that the total area of these spaces is 483 hectares, decreasing by 27 hectares compared to 2011, and represents 28.84% of the total area of the city [11].

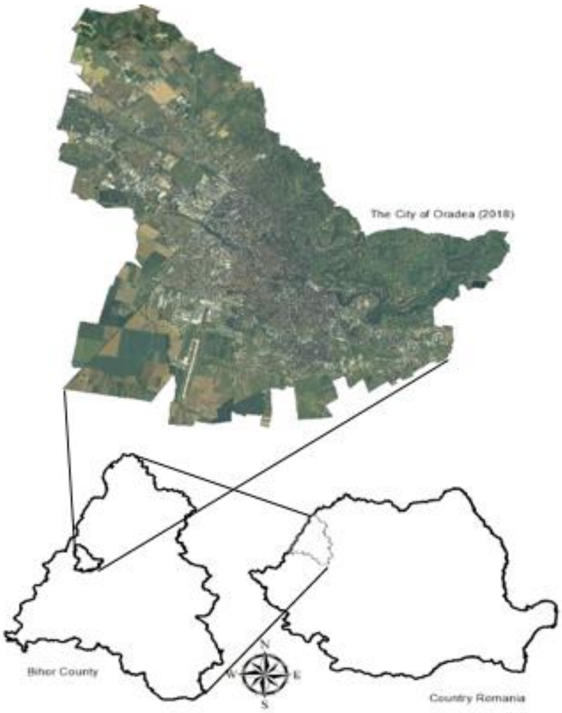

Fig. 1. *The geographic location of The City of Oradea*

2.2. Materials

Landsat 8 is one of the Landsat series of NASA and it was launched on an Atlas-V rocket from Vandenberg Air Force Base, California on 11th February 2013.

Landsat 8 is the most recently launched and operational Landsat satellite and carries the Operational Land Imager (OLI) and the Thermal Infrared Sensor (TIRS) instruments.

Landsat 8 orbits the Earth in a sun-synchronous, near-polar orbit, at an altitude of 705 km (438 mi), inclined at 98.2 degrees, and completes one Earth orbit every 99 minutes. The satellite has a 16-day repeat cycle with an equatorial crossing time: 10:00 a.m. +/- 15 minutes. Landsat 8 has 9 spectral bands for OLI and 2 bands for TIRS. In our study we used band 4 Red (0.64 - 0.67 µm) and band 5 Near - Infrared (0.85 - 0.88 µm) from OLI, and thermal band 10 (10.6 - 11.19 µm) from TIRS. The spatial resolution for all OLI spectral bands is 30 meters and for the TIRS bands is 100 meters [15].

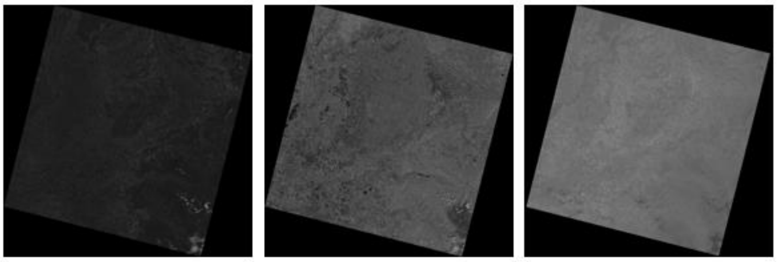

Fig. 2. *The image of the Landsat 8 band 4, band 5 and band 10*

The data from Landsat 8, presented in Figure 2 was downloaded for free from the Earth Explorer portal. The date of acquisition for the bands used in our study is 27th May 2021 [9].

2.3. Data Processing

The single window method used in our study to retrieve the LST values for the City of Oradea with the Landsat 8 data in ArcGIS is based on the algorithm developed by Ugur Avdan and Gordana Jovanovska for Erdas Imagine 2014 software version [7] and involves the accomplish of the following steps presented in Figure 3.

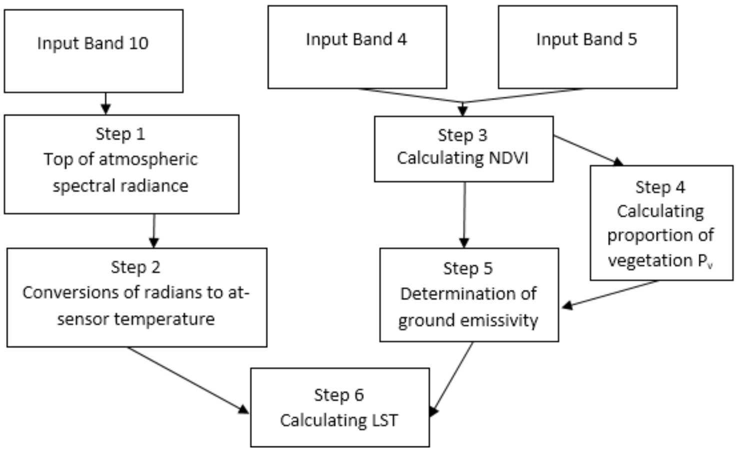

Fig. 3. *Flow Chart* [7]

Step 1: The first step in obtaining the LST consists in retrieving the top of atmospheric (TOA) spectral radiance. We use the following formula [5], [7]:

$$L_\lambda = M_L * Q_{cal} + A_L - Q_i = 0.0003342 * \text{"}band\ 10\text{"} + 0.1 - 0.29, \qquad (1)$$

where: M_L = 0.0003342 - band-specific multiplicative rescaling factor from the metadata (MTL file), Q_{cal} = corresponds to band 10, A_L = 0.1 - band-specific additive rescaling factor from the metadata (MTL file) [8], Q_i = 0.29 - correction for band 10 [1].

The MTL data file from Figure 4 is part of the data package downloaded from the Earth Explorer portal and contains the information regarding parameters that characterize and define the bands.

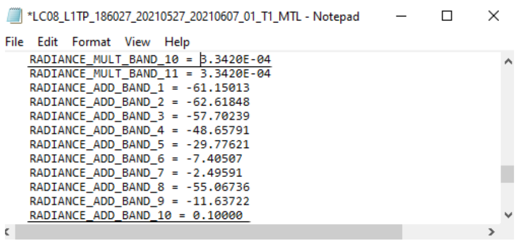

Fig. 1. *Print - screen of the MTL data file with information regarding radiance*

Step 2: After obtaining the top of atmospheric (TOA) spectral radiance L_λ knowing that the thermal band data can be converted from spectral radiance to top of atmosphere brightness temperature in ^{o}C using the thermal constant from Figure 5 we proceed to this conversion revised by adding the absolute zero -273.15 ^{o}C [7], [13]:

$$BT = \frac{K_2}{\ln\left[\left(\frac{K_1}{L_\lambda}\right)+1\right]} - 273.15 = \frac{1321.0789}{\ln\left[\left(\frac{774.8853}{L_\lambda}\right)+1\right]} - 273.15, \quad (2)$$

where: *BT* = Top of atmosphere brightness temperature (^{o}C), K_1 = 774.8853 - band-specific thermal conversion constant from the metadata, K_2 = 1321.0789 - band-specific thermal conversion constant from the metadata [13].

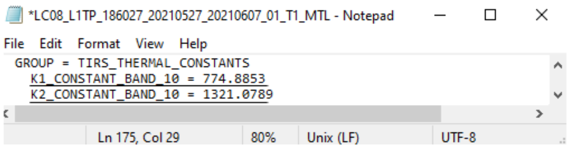

Fig. 5. *Print - screen of the MTL data file with information regarding thermal constant*

Step 3: Following the Figure 3 scheme we proceed to estimate the Normalized Difference Vegetation Index (NDVI). NDVI values range from +1.0 to -1.0. Areas of barren rock, sand, or snow usually show very low NDVI values (for example, 0.1 or less). Sparse vegetation such as shrubs and grasslands or senescing crops may result in moderate NDVI values (approximately 0.2 to 0.5). High NDVI values (approximately 0.6 to 0.9) correspond to dense vegetation such as that found in temperate and tropical forests or crops at their peak growth stage [14]. For the calculation of the NDVI we used the following formula [7]:

$$NDVI = \frac{NIR(band\ 5) - R(band\ 4)}{NIR(band\ 5) + R(band\ 4)}, \quad (3)$$

where NIR represents the near-infrared band and *R* represents the red band.

Step 4: Now that we have the NDVI values we calculate the Proportion of Vegetation (P_v) using the following formula for [7]:

$$P_v = \left(\frac{NDVI - NDVI_s}{NDVI_v - NDVI_s}\right)^2, \quad (4)$$

where NDVI represents the raster obtained in the previous step, $NDVI_s$ = 0.2 represents the value for the soil and $NDVI_v$ = 0.5 represent the value for vegetation.

Step 5: The last step before obtaining the LST is the determination of the ground emissivity. To obtain this value of emissivity we use the following formula [7]:

$$\varepsilon_\lambda = \varepsilon_{v\lambda} * P_v + \varepsilon_{s\lambda}(1 - P_v) + C_\lambda, \quad (5)$$

where ε_s and ε_v are the vegetation and soil emissivities, and *C* represents the surface roughness, considering our case is a homogenous and flat surface we take *C* = 0.005 as a constant [7]. We take into consideration ε_λ based on the NDVI value so for NDVI < $NDVI_s$ the value of the emissivity becomes $\varepsilon_\lambda = \varepsilon_{s\lambda}$, for $NDVI_s \leq NDVI \leq NDVI_v$ emissivity become $\varepsilon_\lambda = \varepsilon_{v\lambda}P_v + \varepsilon_{s\lambda}(1 - P_v) + C$, and for NDVI > $NDVI_v$ emissivity becomes $\varepsilon_\lambda = \varepsilon_{s\lambda} + C$. So for NDVI less than 0 it was assigned the 0.991 value, for values between 0 to 0.2 it was assigned the 0.996 value, for values between 0.2 to 0.5 was used the relation $\varepsilon_\lambda = \varepsilon_{v\lambda}P_v + \varepsilon_{s\lambda}(1 - P_v) + C$, and for NDVI greater than 0.5 it was assigned the 0.973 value [7]. The calculation was done with the conditional "Con" function from the raster calculator.

Step 6: Now that we have all the calculations done, based on the radiative transfer principles [2], we can calculate the land surface temperature (LST) using the following Equation [7], [5]:

$$LST = \frac{BT}{1+w\frac{BT}{p}\ln(\varepsilon_\lambda)}, \quad (6)$$

where: BT represents the brightness temperature, *w* represents the length of the emitted radiation, for band 10 this value is 10.895 µm, *p* represents the constant value obtained by the formula $h * c / \sigma$ (*h* is Plank's constant $6.626 \text{x} 10^{-34}$, *c* is the velocity of light $3*10^8$ m/s, and σ is the Boltzmann constant $1.38 \text{ x } 10^{-23}$ J/K) that when substituting the values the result is 14380 µmK and ε_λ represent the ground emissivity.

3. Results

After completing all the calculating operations we obtained the raster dataset with LST values distribution for the City of Oradea in Figure 6. We observe that on 27th May 2021, we had values of LST between 14 °C and 40 °C.

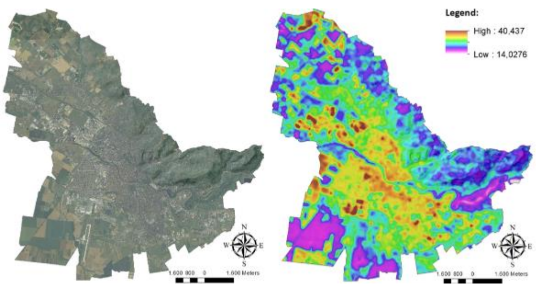

Fig. 6. *Raster dataset with LST values distribution (right) and map of the City of Oradea (left)*

In order to have a proper visualization of the impact of the green spaces on the LST values, we create a section of the LST raster by a line from north to south in Figure 7.

We transformed the raster dataset to features points and selected all the points that are within 5 meters distance to the line. Each point corresponds to a 30 meters raster dataset cell size and has a value of the LST assigned.

As a final visual product, we created a diagram of the extraction line of the LST distribution values in Figure 7. In this diagram from Figure 8, we identified based on the coordinates of the extracted points the objects from the surface that are corresponding to them.

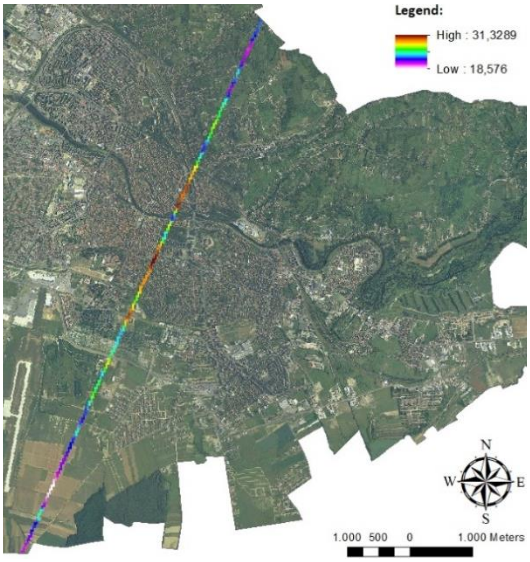

Fig. 7. *Extraction line of LST distribution values*

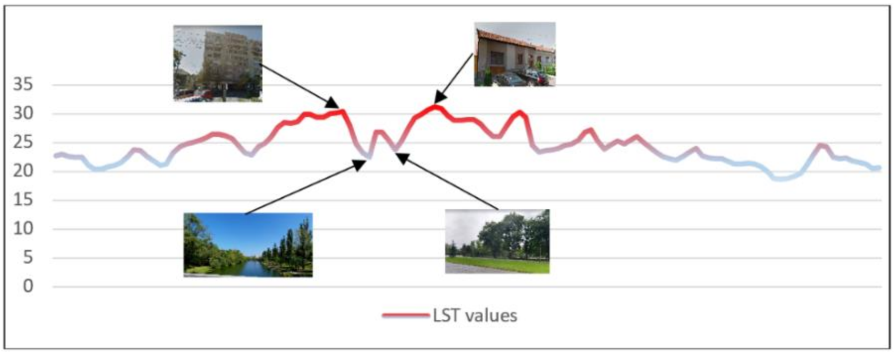

Fig. 8. *Diagram of the extraction line of the LST values*

4. Discussion

In this paper, we observed that satellite data that is free and easy to obtain from specialized online satellite data providers may be used for obtaining powerful information about the correlation between green spaces and land surface temperature (LST). We observed that the Landsat 8 thermal band 10 is suitable to retrieve the land surface temperature and that the ArcGIS software can facilitate this process making it quite accessible.

For the City of Oradea area, we observed based on the distribution of the LST that in dense residential neighborhoods, roads, and other transportation infrastructures and areas with bare soil we meet the highest values, and in areas with many trees and other kinds of vegetation like parks and the banks of the rivers these values can drop even with 10-20 ^{o}C.

Knowing that land surface temperature does not represent the real temperature that people feel but can have a major impact on that, with satellite data the actors involved in improving the standards of living can have a really powerful tool to help them in creating the proper urban planning.

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