Analysis of Urban Heat Islands Using Landsat 8 OLI / TIR Data: Case of the City of Guelma (Algeria)

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Authors’ contributions

This work was carried out in collaboration among all the authors. Author BK designed the study, carried out the mapping, carried out the statistical analysis. Author YB is responsible for managing the article and improving the linguistic content. Author NM managed the documentary researches and the verification of the field of the study. Author KB supervised the work, wrote the first draft of the manuscript and the analyzes of the study. All authors read and approved the final manuscript.

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ABSTRACT

This study aims to analyze the urban heat islands of the city of Guelma using Landsat 8 data and the geographic information system. The application of the single Chanel algorithm has been applied to extract surface temperature (LST) from Landsat 8 data. The result obtained shows that the surface temperature of August 11, 2019 in the city of Guelma varied from 36 to 47 degrees. However, the correlation between the LST, the NDVI and the NDBI allowed characterizing the effects of the green zones and the water resources thus the grounds built on the urban heat islands. The ecological assessment was performed using an urban thermal field variance index (UTFVI). The result obtained from this ecological assessment shows that 4 km² of the surface of the city of Guelma represents a much worse ecological quality. It is therefore urgent for this city to strengthen and expand the strategies for reducing the effects of urban heat islands for preserve the quality of urban life of the inhabitants.

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1. INTRODUCTION

It is known that urbanization can have major impacts on local meteorological and climatic conditions [1]. Among these impacts are the urban heat islands [2], which have a direct influence on the degradation of the environment [3]. An urban heat island is an urbanized area where temperatures are higher than in the surrounding areas [4]. Currently, with the development of society and the acceleration of the urbanization process, the urban heat island has become increasingly important. It has had significant effects on urban development and the environment of human life [5]. However, in urban areas, buildings, concrete, tar and industrial activity are the source of the urban heat island. Replacing natural vegetation cover with buildings, sidewalks, and other infrastructure creates natural cooling effects. In addition, the heat given off by vehicles, factories and air conditioners, accentuating the effects of urban heat islands. In addition, tall buildings and narrow streets can heat the air [6]. The high use of energy for cooling in cities with heat islands causes poor air quality which directly affects human health and promotes asthma and respiratory diseases. Recently there has been a lot of research on temperature recovery by remote sensing. A study carried out by [7] performed three different methods (a radiative transfer equation (RTE) method, two single window algorithm methods) to recover the temperature of the soil surface and demonstrated that the accuracy of the results of temperature recovered by remote sensing data is acceptable compared to actual temperature data. In Italy, [8] used LandSat 8 OLI / TIRS data for an analytical study of the land surface temperature with NDVI and NDBI in Florence and Naples. In Chicago, USA, [9] used LandSat TM and OLI / TIRS data to evaluate the urban heat islands ecologically. In Romania [10] based on LandSat 8 OLI / TIRS data to compare NDBI and NDVI as indicators of the urban heat island effect in Iasi. In Hong Kong [6] used Aster and LandSat TM data to analyze urban heat island. In Algeria, like the Maghreb and African countries, there are few studies on the phenomenon of urban heat islands using remote sensing data [11]. The city of Guelma is an illustrative example of this phenomenon where the average maximum temperature reaches 45 ° C in the months of June, July and August. This city experienced remarkable urban sprawl between 1987 and 2015, an increase of 1,516.56 ha against a regression in the area of agricultural land and forests [12]. Faced with the rapid urbanization of this city where all the conditions for the effects of urban heat islands are met, especially during the summer season, it has become necessary to conduct research on the analysis of urban heat islands to set up a urban planning compatible with environmental protection in the future. This study is based on the analysis of urban heat islands using remote sensing data (Landsat image of 07/23/2018) by calculating the surface temperature (LST) and using the single method Channel which requires having the values of the emissivity of the surface [13], the main objective of which is to improve knowledge of the urban heat island phenomenon and the impact of heat waves and heat on a population more or less vulnerable to this type of hazard.

2. MATERIALS AND METHODS

2.1 Presentation of the Study Area

The city of Guelma is extended in the valley of Oued Seybouse in the heart of a large agricultural region at 290 m above sea level, it is located in the northeast of Algeria bounded by the following geographic coordinates: latitude: between 36 ° 28'12.12 "N and 36 ° 26'9.36" N, longitude: between 7 ° 28'10.72 "E and 7 ° 23'46.44" E [14].

Surrounded by mountains of Mahouna, Debagh and Houara, Guelma is limited to the north by Oued Seybouse, to the east by Oued el Maiz and the town of Belkheir, to the south by the mountains of Mahouna and to the west by the plain of Ben Tabouche Fig. 1. The climate is of the Mediterranean sub humid type with a rainy period from October to April and a dry period from May to September, with rainfall amounts varying between 450 and 600 mm / year. The average annual temperature is around 18°C. The hottest months are July and August when the average temperature hovers around 26°C. The coldest months are December and January with average temperatures around 12.1°C. It covers an area of 15 km² for a population of 137 971 inhabitants in 2018, a density which reaches 9 198 inhabitants / km² [14]. It is a city of transition in the northeast region of Algeria; it is connected to the coastal Wilayas (el taref, Annaba and Skikda) and the wilaya of the interior region (Constantine, Souk Ahras and Oum El Bouaghi).
2.2 The data

In such a study, as in the case of the city of Guelma, it is necessary to be able to analyze urban heat islands to use geographic information systems and remote sensing. This study is based on the processing and analysis of an image of the Landsat program acquired on August 11, 2019 using software: ArGSI10.3 and ENVI 5.3. The base satellite image of this work is downloadable free of charge from the website www. Earth Explorer's main features are summarized in Table 1.

2.3 METHODOLOGY

The Landsat 8 OLI / RIRS sensor is made up of 11 spectral bands with different spatial resolution. The thermal infrared band (100 m resolution) is resembled at a resolution of 30 meters for a good combination with the other bands used so as to avoid any affection of the raster data during the calculation operations. The resolution of the work is therefore 30 m, and the projection system applied to all our data is Universal Transverse of Mercator zone 32 north. To analyze the urban heat islands at the level of the study area, indices such as NDVI and NDBI were applied to determine the correlation with the land surface temperature (LST), while the Urban Thermal Field Variance Index (UTFVI) was used for the ecological evaluation of the urban heat island zones of the city of Guelma during a dry summer month. The flowchart of the Land Surface Temperature (LST) algorithm retrieval is given in Fig. 2.

2.3.1 Calculation of the land surface temperature LST)

The land surface temperature for the city of Guelma was extracted from the spectral band 10 of the Landsat 8 OLI / TIRS image using the following algorithms [15]:

2.3.2 Conversion of the DN values into spectral radiance

To calculate the light temperature from the Landsat thermal bands, you must first convert the DN values of the Landsat 8 thermal band into spectral radiance. The formula for converting DN into spectral energy radiation in the upper atmosphere is as follows [16]:

\[ L\lambda = 0.0003342 \times DN + 0.1 \]  

(1)

Where,

\( L\lambda \): is the spectral radiance at the Landsat 8 OLI / TIRS 10 sensor.

DN: Band 10 of thermal infrared.
Table 1. Landsat 8 OLI / TIRS spectral bands used

<table>
<thead>
<tr>
<th>Sensor</th>
<th>Path/Row</th>
<th>Acquisition date</th>
<th>Time</th>
<th>Sun elevation (°)</th>
<th>Sun azimuth (°)</th>
<th>Cloud cover (%)</th>
<th>Bands used</th>
<th>Electromagnetic Spectrum domain</th>
<th>Spectral bands</th>
<th>Resolution (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>OLI/TIRS</td>
<td>193/035</td>
<td>11/08/2019</td>
<td>10:07:42</td>
<td>01/03/1900</td>
<td>09/05/1900</td>
<td>0</td>
<td>4</td>
<td>Red</td>
<td>0.630–0.680</td>
<td>30</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>5</td>
<td>Near Infrared</td>
<td>0.845–0.885</td>
<td>30</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>6</td>
<td>Short Wave Infrared</td>
<td>1.560–1.660</td>
<td>30</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>10</td>
<td>Thermal Infrared</td>
<td>10.6-11.2</td>
<td>100</td>
</tr>
</tbody>
</table>
2.3.3 Conversion of spectral radiance to temperature in degrees (° C)

The spectral radiance can be converted into a light temperature in Celsius using the following formula [16]:

\[ T = \frac{K_2}{ln \left( \frac{K_1}{T} + 1 \right)} - 273.15 \]  

(2)

Where,

- \( T \): is the brightness temperature in degrees (°C)
- \( L_\lambda \): is the spectral radiance at the Landsat 8 OLI / TIRS 10 sensor
- \( K_1 \): Calibration constant 1
- \( K_2 \): Calibration constant 2

The values of \( K_1 \) and \( K_2 \) from band 10 of the Landsat 8 sensor for our study area are extracted from the metadata file.

2.3.4 Calculation of the surface emissivity

One of the most widely used vegetation indices for estimating surface emissivity is the Normalized Difference Vegetation Index (NDVI). The proportion of vegetation (PV) of each pixel was determined from the NDVI using the following equation [17]:

\[ E = 0.0004 \times PV + 0.986 \]  

(3)

Such that

- \( E \): emissivity
- \( PV \): Proportion of vegetation

\[ PV = \frac{(NDVI - NDVI_{min})}{(NDVI_{max} - NDVI_{min})}^2 \]  

(4) Such that

\[ NDVI = \frac{(NIR - R)}{(NIR + R)} \]  

(5)

where

- \( NIR \): Near infrared channel (B5) for Landsat8 OLI / TIRS
- \( R \): Red channel (B4) for Landsat8 OLI / TIRS

Finally, the land surface temperature (LST) is calculated according to the following formula [18]:

\[ LST = \frac{T}{1 + (\frac{\lambda}{k} + 1) \times \ln E} \]  

(6)

Where,

- \( LST \): is the land surface temperature in degree (°C)
- \( T \): is the brightness temperature in degrees (°C)
- \( \lambda \): is the wavelength of the spectral band (B10) of the Landsat 8 sensor.
- \( \sigma \): is the Boltzmann constant (1.38 \times 10^{-23} \text{ J / K})
- \( h \): is Plank's constant (6,626 \times 10^{-34} \text{ Js})
- \( c \): is the speed of light in a vacuum (2.998 \times 10^{-8} \text{ m / s})
- \( E \): is emissivity.

3. RESULTS AND DISCUSSION

3.1 Analyses of Urban Heat Islands in the City of Guelma

The spatial distribution of the land surface temperature of the city of Guelma is illustrated in Fig. 3. The results obtained show that the
average LST is 40.43°C, the maximum and minimum LST is 36°C and 47°C, respectively. The highest LST dominates the northeast of the city, while the western and southern part represents the low LST. The impact of urban heat islands in urban areas depends on the density of the population with medium-sized buildings. In Guelma, the West, Center and South-West districts are less populated and have green zones compared to the North-East, East and South districts which explains why the values of the LST are higher in these zones compared on the west, center and south-west side. The presence of Oued Seybouse in the northwest has moderated the microclimate in this part of the city. In general, most of the city of Guelma undergoes varied temperatures of 36 to 41°C or 66.66% of the total surface of the city. These LST values are generally found in the surrounding areas of Oued Seybouse, green spaces and larger residential areas. The values of the LST, varied between 41 and 47°C, occupies 33.34% of the total surface of the city, they are located mainly in the zones of certain industrial complexes, the concentration of steels and concretes and close fertile agricultural land of black color which strongly absorbs thermal radiation emitted by the hot plasma of the Sun.

To confirm this first analysis, a supervised classification of the basic image of this study is carried out. The Fig. 4 shows the different land use units in the city of Guelma. The superimposition of the land surface temperature map and that of the land use, made it possible to show that the values of the LST in built up and bare soil vary from 41°C to 47°C. these two land use units generally represent the concentration of human activities (Constructions, urban transport, industry, housing estate) where the use of energy is very high. Unlike the green zones (vegetation) the LST values are varied from 36°C to 39°C.

Fig. 3. Land surface temperature (LST) of the city of Guelma August 11, 2019
3.2 Correlations between Urban Heat Island (LST), NDVI and NDBI

The NDVI (Normalized Difference Vegetation Index) is one of the most widely used vegetation indices for enhancing vegetation information [3]. On the other hand, the NDBI (Normalized Difference Built-up Index) is one of the indices used to extract built-up land from urban areas. [3] The NDBI is calculated by the following formula:

\[
\text{NDBI} = \frac{\text{MIR} - \text{NIR}}{\text{MIR} + \text{NIR}}
\]  

(7)

Where,

NIR: Near infrared channel (B5) for Landsat8 OLI / TIRS
MIR: Mid-infrared channel (B6) for Landsat8 OLI / TIRS

To compare the effects of green zones and built-up areas to urban heat islands providing useful information for urban development and environmental protection, we have correlated LST and NDVI, NDBI. Table 2 summarizes the result of this correlation.

The correlation coefficient between LST and NDVI is -0.09, while that of LST and NDBI is 0.38. The negative correlation between LST and NDVI indicates that the impact of green zones and water resources on urban heat islands is negative, which means that these zones can reduce the effects of urban heat islands. On the contrary, the positive correlation between the LST and the NDBI suggests that built-up land can reinforce the effects of urban heat islands.

Table 2. Correlation between LST, NDVI and NDBI

<table>
<thead>
<tr>
<th>Correlation parameter</th>
<th>LST</th>
<th>NDVI</th>
<th>NDBI</th>
</tr>
</thead>
<tbody>
<tr>
<td>LST</td>
<td>1</td>
<td>-0.09</td>
<td>0.38</td>
</tr>
<tr>
<td>NDVI</td>
<td>-0.09</td>
<td>1</td>
<td>-0.8</td>
</tr>
<tr>
<td>NDBI</td>
<td>0.38</td>
<td>-0.8</td>
<td>1</td>
</tr>
</tbody>
</table>
3.3 Ecological Evaluation of the Urban Heat Island in the City of Guelma

The Urban Thermal Field Variant Index (UTFVI) is commonly used to assess the effects of urban heat island [18]. It can be calculated by the following equation:

\[
\text{UTFVI} = \frac{\text{T}_s - \text{T}_m}{\text{T}_m} \quad [19]
\]

(8)

Where,

UTFVI: Urban Thermal Field Variance Index

Ts: Land surface temperature in degrees (°C)

Tm: The average of land surface temperature in degrees (°C).

The Urban Thermal Field Variance Index can be subdivided into six levels in accordance with six different ecological assessment indices [18]. The Table 3 indicates the specific thresholds for the six levels of the Urban Thermal Field Variance Index [6].

The quantitative ecological assessment of the effects of urban heat islands in the city of Guelma is illustrated in Fig. 5.

<table>
<thead>
<tr>
<th>UTFVI</th>
<th>Urban Heat Island phenomenon</th>
<th>Ecological evaluation index</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt; 0</td>
<td>None</td>
<td>Excellent</td>
</tr>
<tr>
<td>0.000 - 0.005</td>
<td>Weak</td>
<td>Good</td>
</tr>
<tr>
<td>0.005 - 0.010</td>
<td>Middle</td>
<td>Normal</td>
</tr>
<tr>
<td>0.010 - 0.015</td>
<td>Strong</td>
<td>Bad</td>
</tr>
<tr>
<td>0.015 - 0.020</td>
<td>Stronger</td>
<td>Worse</td>
</tr>
<tr>
<td>&gt; 0.020</td>
<td>Strongest</td>
<td>Worst</td>
</tr>
</tbody>
</table>

Table 3. Interpretation of the quantitative assessment index for the ecological effects of the city of Guelma

Fig. 5. Ecological evaluation index (UTFVI) of the city of Guelma in August 2019
According to the urban thermal fields variance index (UTFVI) which measures the ecological quality of life in urban areas in terms of degree of thermal comfort compared to the existence of the phenomenon of urban heat islands, variable impacts of the heat islands heat have been detected in Guelma. The city of Guelma has two extremes: areas of thermal stress (i.e., UTFVI > 0.02 or 4 km² of the total area of the city) and areas with optimal microclimate (i.e., UTFVI < 0 or 2 km² of total area of the study area) (Fig. 5 and Table 3). The ecological assessment map of the classification established by the UTFVI of the city of Guelma can also provide useful information to managers of the urban environment to assess the quality of the eco-environment. The serious urban heat island phenomenon requires more reasonable urban planning and urban development in order to protect such an ecological environment in the future urban plan of the city of Guelma.

4. CONCLUSION

The LST extracted from Landsat 8 in August 2019 using the single-channel algorithm, shows a variable distribution of the urban heat island phenomenon in the city of Guelma. The extracted temperature values show that the distribution of urban heat islands in Guelma is generally localized in the South-East, East and North-East part. This value is explained by the presence of populated districts, concentration of steel and concrete, installation of certain industrial complexes and the proximity of fertile agricultural land (black soil). In addition, the correlation analysis between calculated LST, NDVI and NDBI has shown that green areas and water resources can lessen the effects of urban heat islands, while built-up land can accelerate the effects. In addition, the calculation of the ecological assessment index shows that the city of Guelma experiences the strongest phenomenon of urban heat islands and the worst eco-environment, which urgently requires reasonable urban planning for development urban in line with environmental quality in the future. It is therefore important for the city of Guelma to strengthen and broaden the strategies to reduce the effects of urban heat islands to preserve the quality of urban life for residents.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

REFERENCES

10. Macarof P, Statescu F.Comparison of NDBI and NDVI as indicators of surface urban heat island effect in Landsat 8 imagery: A case study of Iasi. PESD. 2017;11(2).


16. USGS. Using the USGS Landsat Level-1 Data Product; 2019.


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