http://dx.doi.org/10.15576/GLL/2023.3.61

GLL

Geomatics, Landmanagement and Landscape No. 3 • 2023, 61–72

USE OF REMOTE SENSING AS AN INDICATOR OF THE URBAN HEAT ISLAND EFFECT: THE CASE OF THE MUNICIPALITY OF GUELMA (NORTH-EAST OF ALGERIA)

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Summary

The main objective of this study is to show which of the LST-NDVI and LST-NDBI relationships can determine the most accurate index that can be used as an indicator of the effects of urban heat islands in the municipality of Guelma, using Landsat data. 8 OLI/TIRS and the geographic information system. The application of the calculation formulas made it possible to extract the Land Surface Temperature (LST), Normalized Difference Vegetation Index (NDVI) and Normalized Difference Built up Index (NDBI) of the municipality of Guelma for the four seasons of 2019. This calculation led to the determination of the relationship between all three indicators. The results obtained show a strong correlation between the LST and the NDBI for the four seasons of the year. They suggest that the NDBI is an accurate indicator of the heat island effect in Guelma. This indicator can serve as a tool for future urban planning by those in charge of this department. However, there is currently and urgent need to strengthen strategies for reducing the effects of urban heat islands in order to preserve the quality of urban life of the inhabitants and by setting up emergency programs.

Keywords

Landsat 8 • LST • NDVI • NDBI • Guelma • Algeria

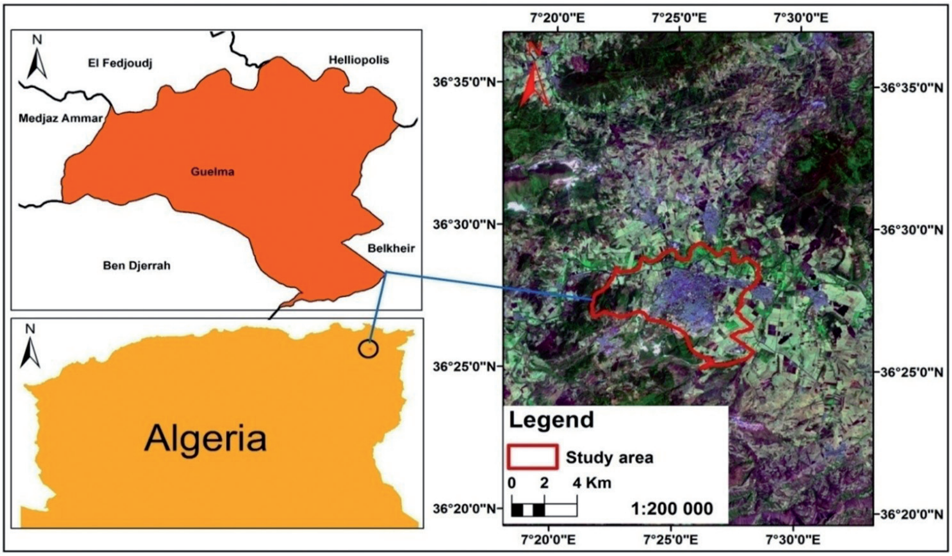
1. Introduction

In both developed and developing countries, most urban areas have grown at a rapid pace [Khalaf 2016]. Urban development and expansion reduces the natural vegetation cover and replaces it with a different interface of synthetic components (such as structures, roads, modern zones, etc.). This tendency is also indicated by changes in atmosphere due to new land use and changes in vegetation cover that cause the effects of the urban heat island [Khalid 2014]. The urban heat island effect (UHI) is an atmospheric phenomenon in which the ground surface temperatures are higher in urban areas than in rural areas [Kleerekoper et al. 2011, Tsou et al. 2017, Macarof and Statescu 2017]. One of the main causes of the urban heat island is urbanization, as urban heat is eradiated by buildings and the ground, which releases the heat stored during the day. The solar energy absorbed or reflected varies according to the albedo and the thermal inertia of the frame [Zoca and Papin 2014]. The urban heat island effect is a factor that has to be taken into account in the design and management of cities. However, it is clear that various urban policies are still far from really taking this phenomenon into account, which will be even more prevalent in the future if nothing is done today [Valette and Cordeau 2010]. As these urban environmental problems become more severe, the effects caused by urban heat islands are also becoming a major concern for the urban climate and environment [Peyrache-Gadeau et al. 2011]. The application of the remote sensing technology has become important for research on urban heat island. Studies of urban heat islands are increasingly important today, thanks to the development of remote sensing technology and computational tools [Wang et al. 2016]. In this context, several studies on thermal remote sensing have been using the Normalized Deference Vegetation Index (NDVI) as the main indicator of urban climate. The negative correlation between the LST and the NDVI is more valuable for studies of the urban climate [Yuan et al. 2007]. For [Yue et al. 2007] the average values of the LST and the NDVI for different types of land use are very different. In other studies [Sun et al. 2007] the correlation between the LST and the NDVI is positive for the hot season and negative for the cold season. According to [Yuan et al. 2007] the NDVI alone could not be a sufficient measure to quantitatively study the urban surface heat island. Using the Landsat TM and ETM + data to study the relationship between the LST and the percentage of impermeable surface in an urban environment, it was found that for the four seasons of the same year there is a strong linear relationship between the LST and the percentage of impermeable surface [Liu et al. 2011]. One of the main types of land cover, especially in built-up areas, is the Normalized Difference Built-up Index (NDBI). It is therefore possible to replace the percentage of impermeable surface by the NDBI to study the urban heat island effect. This index (NDBI) can also be used as an indicator of the impermeable surface in urban areas [Yuan et al. 2015]. The municipality of Guelma is one of the municipalities of eastern Algeria which is characterized by very high maximum temperatures, reaching up to 48°C in the months of July and August. It is located in an agricultural region around an excellent thermal area (Hammam Debagh). The replacement of natural plant cover with buildings, sidewalks, and other infrastructure is causing natural cooling effects in this municipality, especially in the months of July and August. In addition, the heat emitted by vehicles, factories and air conditioners exacerbates the urban heat island effect. The aim of this study is to determine the relationship between the LST, NDVI and NDBI by using the municipality of Guelma as a case study, using images from the Landsat 8 program for the four seasons of 2019.

2. Material and methods

2.1. Study area

The municipality of Guelma stretches into 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 delimited by the following geographic coordinates: latitude: between 36°29'55.39" N and 36°24'54.80" N, longitude: between 7°29'3.90" E and 7°21'15.65" E (Fig. 1). Surrounded by mountains of Mahouna, Debagh and Houara, the municipality of Guelma is bordered to the north by the municipalities of Héliopolis and El-Fedjoudj, in the south by the municipality of Bendjerah, in the east by the municipality of Belkheir, and in the west by the municipality of Medjez Amar. The climate is Mediterranean sub humid, with a rainy period from October to April and a dry period from May to September, with rainfall varying between 450 and 600 mm/year [Khallef et al. 2020]. The average annual temperature is around 18°C. The hottest months are July and August with the average temperature around 26°C. The coldest months are December and January with average temperatures around 12.1°C [Khallef et al. 2020]. It covers an area of 44,82 km^2. It is a transitional municipality in the north-eastern region of Algeria; it is linked to the coastal wilayas (El Taref, Annaba and Skikda) and the wilayas of the interior region (Constantine, Souk Ahras and Oum el Bouaghi).



Source: Author's own study

Fig. 1. Location of the municipality of Guelma

2.2. The data

Studying such cases as the municipality of Guelma, it is necessary to be able to determine the relationships between the LST, NDVI and the NDBI to use remote sensing and geographic information systems. This study is based on the processing of Landsat program images acquired during the four seasons (winter, spring, summer and autumn) of 2019 using the software: ArcGis10.3 and ENVI 5.3. The basic satellite images for this study have been downloaded free of charge from Earth Explorer (Table 1).

Table 1. The Landsat 8 OLI / TIRS images

Sensor	Seasons	Acquisition date	Path	Row
Landsat 8 OLI/TIRS	Winter	16/02/2019	193	35
	Spring	04/03/2019	193	35
	Summer	26/07/2019	193	35
	Autumn	14/10/2019	193	35

Source: Author's own study

2.3. Methodology

The methodology used is based on the preprocessing and processing of the selected images followed by the calculation of the surface temperature and indices such as NDVI and NDBI.

2.3.1. Conversion of DN values in spectral radiance

To calculate the Top of Atmosphere (TOA) Radiance, the thermal infra-red digital numbers can be converted to the TOA spectral radiance by the following formula [USGS 2019]:

$$L\lambda = 0.0003342 \cdot DN + 0.1 \tag{1}$$

where:

- $L\lambda$ – the spectral radiance at the Landsat 8 OLI / TIRS 10 sensor,
- DN – Band 10 of thermal infrared.

2.3.2. Conversion of spectral radiance to temperature in degrees (C°)

The spectral radiance can be converted to the top of the atmosphere brightness temperature in Celsius using the following formula [USGS 2019]:

$$BT = \frac{K2}{\ln\left(\left(\frac{K1}{L\lambda}\right)+1\right)} - 273.15 \tag{2}$$

where:

- BT – top of atmosphere brightness temperature (°C),
- $L\lambda$ – TOA spectral radiance (Watts/($m^2 \cdot sr \cdot \mu m$),
- K1 – calibration constant 1,
- K2 – calibration constant 2.

The values of K1 and K2 are extracted from the metadata file.

2.3.3. Calculation of 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) for each pixel was determined from the NDVI using the following equation [Carlson et al. 1997]:

$$E = 0.004 \cdot PV + 0.986 \tag{3}$$

where:

E – emissivity,
PV – proportion of vegetation calculated by the following equation:

$$PV = ((NDVI - NDVI_{min})/(NDVI_{max} - NDVI_{min}))\ 2 \tag{4}$$

where:

NDVI – DN values from NDVI image,
$NDVI_{min}$ – minimum DN values from NDVI image,
$NDVI_{max}$ – maximum DN values from NDVI image.

2.3.4. Land Surface Temperature (LST)

The land surface temperature is calculated using the following formula [Weng et al. 2003]:

$$LST = BT/\ (1 + (10.8 \cdot BT/14388) \cdot Ln(E)) \tag{5}$$

where:

BT – top of atmosphere brightness temperature (°C),
E – land surface emissivity.

2.3.5. The Normalized Difference Vegetation Index (NDVI)

The normalized difference vegetation index generates an image showing the vegetation cover. It is an index that uses the visible bands and the near infrared of the electromagnetic spectrum [Rouse et al. 1973]. The NDVI values are between –1 and 1, the negative values of which correspond to areas other than vegetation cover. Its formula is written as follows:

$$NDVI = \frac{NIR - R}{NIR + R} \tag{6}$$

where:

NIR – Near Infrared (Band 5 for Landsat 8),
R – Red (Band 4 for Landsat 8).

2.3.6. The Normalized Difference Built-up Index (NDBI)

This index was formulated by [Zha et al. 2013] to extract the built-up areas from the near infrared and short infrared spectral bands according to the following formula:

$$NDBI = \frac{SWIR - NIR}{SWIR + NIR} \tag{7}$$

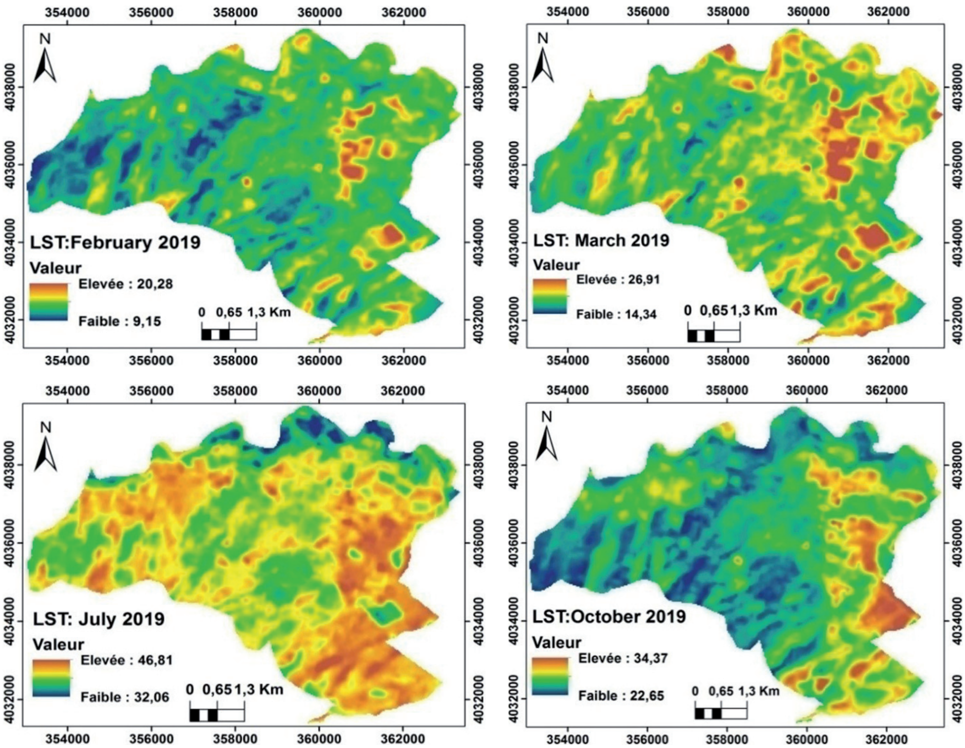
where:

SWIR – Shortwave Infrared (Band 6 for Landsat 8),
NIR – Near Infrared (Band 5 for Landsat 8).

3. Results and discussion

3.1. Land surface temperature (LST)

Obtaining the land surface temperature and using it in the various analyzes is very important in determining problems related to the environment [Orhan et al. 2014]. In the case of the municipality of Guelma, the LST is calculated from Landsat 8 data (Fig. 2).



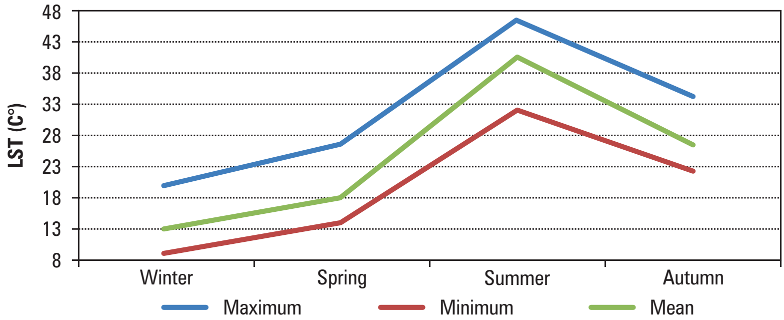
Source: Author's own study

Fig. 2. LST map for the four seasons of 2019

Figure 3 shows the variations of the LST for the four seasons of 2019. The maximums are recorded in summer and autumn when the LST is above 33°C with average values above the maximums for the winter and spring seasons. These variations are indicative of the Mediterranean climate, which is characterized by hot and dry seasons and other cold and rainy seasons.

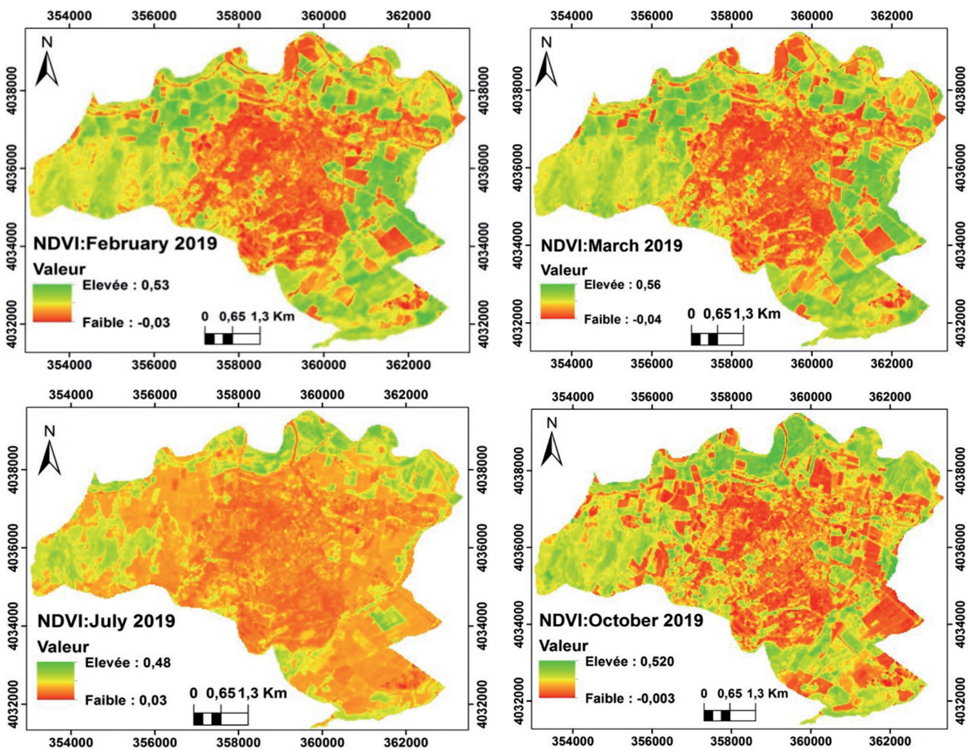
3.2. The Normalized Difference Vegetation Index (NDVI)

Calculated according to the formula N 6, the NDVI obtained for the four seasons (Fig. 4) shows that this index is higher in spring and winter (vegetative period) than in summer and autumn. The maximum NDVI values are 0.53 higher in winter and spring, with average varies from 0.22 in winter to 0.25 in the spring. This variation indicates that the NDVI has a seasonal variation (Fig. 5).



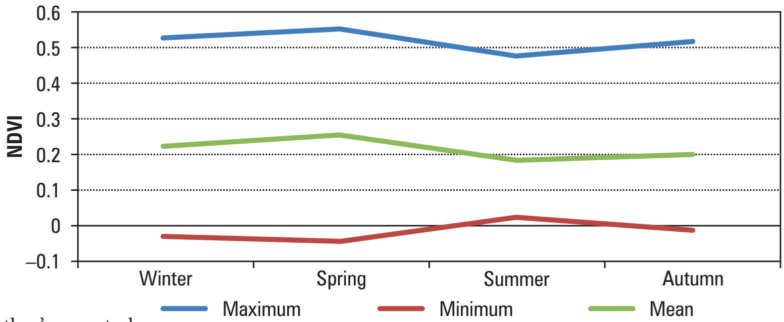
Source: Author's own study

Fig. 3. Variation of the LST for the four seasons of 2019



Source: Author's own study

Fig. 4. NDVI map for the four seasons of 2019

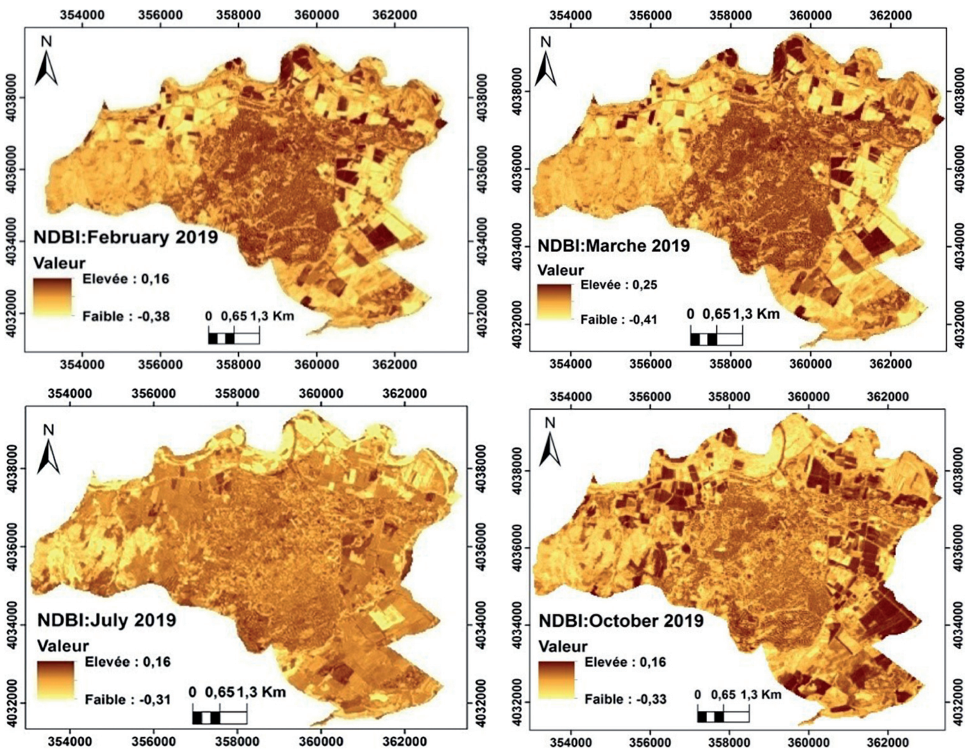


Source: Author's own study

Fig. 5. Variation of the NDVI for the four seasons of 2019

3.3. The Normalized Difference Built-up Index (NDBI)

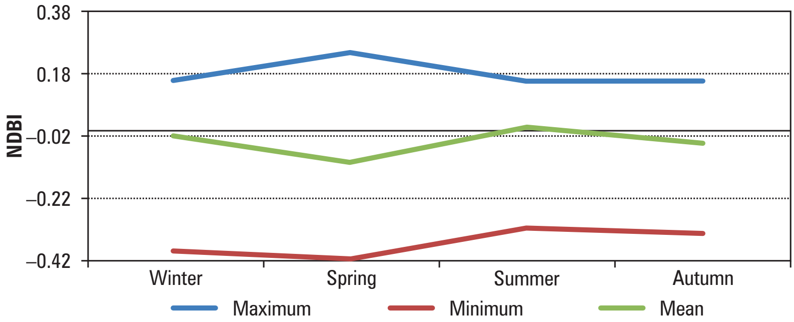
The NDBI highlights urban areas with higher reflectance in shortwave infrared radiation [Bhatti et al. 2014]. Based on formula number 7, the result obtained from the NDBI for the four seasons is illustrated in Figure 6.



Source: Author's own study

Fig. 6. Variation of the NDBI for the four seasons of 2019

Figure 7 shows that the highest NDBI values represent the built-up areas and the minimum values indicate the vegetation areas. The maximum NDBI values for the summer, autumn and winter seasons are fairly close (0.16). This value is varied in spring (vegetative period) to reach 0.25. This result indicates that the NDBI has only one seasonal variation influenced by the vegetative period of greenery.



Source: Author's own study

Fig. 7. Variation of the NDBI for the four seasons of 2019

3.4. Relationship between LST, NDVI and NDBI

To study the relationships between LST, NDVI and NDBI, a correlation between the three indicators is determined. Table 2 shows that the correlation between the LST and the NDBI is very strong for all the seasons, while that between the LST and the NDVI is very weak for the four seasons. The negative relationship between the LST and the NDVI indicates demonstrates that the effect of vegetation and water resources on the urban heat island is negative, which means that these areas can reduce the urban heat island effect. Conversely, the positive relationship between LST and NDBI indicates that built-up land can reinforce the impacts of urban heat islands. In the case of our study area, this result indicates that the NDBI can be used to analyze the effects of urban heat islands during all seasons of the year.

Table 2. Correlation between LST, NDVI and NDBI

Seasons	Layer	LST	NDVI	NDBI
Winter	LST	1	–0 .11	0.31
	NDVI	–0.11	1	–0.94
	NDBI	0.31	–0.94	1
Spring	Layer	LST	NDVI	NDBI
	LST	1	–0.28	0.43
	NDVI	–0.28	1	–0.95
	NDBI	0.43	–0.95	1

Table 2. cont.

Seasons	Layer	LST	NDVI	NDBI
Summer	Layer	LST	NDVI	NDBI
	LST	1	–0.46	0.60
	NDVI	–0.46	1	–0.90
	NDBI	0.60	–0.90	1
Autumn	Layer	LST	NDVI	NDBI
	LST	1	–0.32	0.54
	NDVI	–0.32	1	–0.89
	NDBI	0.54	–0.89	1

4. Conclusion

This aim of the study was to investigate the relationships between the LST, NDVI and the NDBI in the municipality of Guelma using Landsat 8 OLI/TIRS data and geographic information systems. The results obtained show that the land surface temperature and the NDVI vary according to the season of the year, while the NDBI varies according to the vegetative period (spring). The correlation between LST, NDVI and NDBI indicates that there is a strong relationship between the LST and the NDBI for the four seasons while the relationship between the LST and the NDVI varies in Guelma only during the vegetative period (spring). The strong correlation between the LST and NDBI indicates that urban areas are responsible for variations in the dynamics of surface temperatures. However, the NDBI is an accurate indicator of the urban heat island effect. Moreover, the city of Guelma is well known for the urban heat island phenomenon, thus it urgently requires proper urban planning for urban development in line with environmental quality in the future. It is therefore important for this city to strengthen and expand the strategies for reducing the effects caused by urban heat islands by developing green areas, using reflective materials on the surface, building on high ground, installing freshness, promoting sustainable transport, and encouraging the use of renewable energies. All these suggestions can preserve the quality of urban life of the inhabitants.

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