Analyzing Monterrey blue/green infrastructure for the mitigation of heat islands using Earth Observation and WUDAPT method

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Abstract

The Metropolitan Area of Monterrey has grown excessively along with its population in recent decades, resulting in an urban area with problems of distribution of spaces and services. In addition to this, factors such as pollution resulting from industrial activities and the reduction of green areas are related to the increase in temperatures in the area and the creation of urban heat islands, which are mitigated by the cooling action provided by the green/blue infrastructure of urban rivers. Because the rivers in the study area do not have a continuous channel throughout the year and the water supply problems that have recently worsened due to the drought in the north of the country, the riparian vegetation of its 3 rivers (Pesqueria, Santa Catarina and La Silla) plays a crucial role in reducing temperatures by acting as a natural heat sink, so its conservation and restoration is essential. In this research, the influence of rapid urbanization on the deterioration of rivers during 2003, 2013 and 2021 was evaluated using Google Earth Engine and the WUDAPT scheme for local climatic zones, finding that there is a correspondence between local climatic zones and fluctuations in temperature. The results obtained over a period of approximately two decades indicate that natural climate zones register lower temperatures compared to impervious surfaces, and that there is also considerable variation between areas with dense green/blue infrastructure and natural covers with little or no vegetation, since the latter have temperatures similar to those of the built classes.

1. Introduction

The rapid increase in urban areas has meant excessive growth in which aspects such as road planning, distribution of services, sufficient housing spaces, among others, are not considered. In the case of the Monterrey Metropolitan Area (MMA) in Northeast, Mexico, these problems are evident in situations such as water shortages, lack of urban planning, pollution, and reduction of green areas. Currently, Monterrey and its surrounding municipalities present environmental problems that have brought with them constant poor air quality and a significant increase in temperature. These negative effects can be counteracted thanks to the action of vegetation, green areas and even the presence of bodies of water, since the spatial morphologies of green spaces generate cooling effects that mitigate urban heat islands (UHI) in cities (Jiang et al., 2021).

The urban area of the MMA is so large that the action of green areas and bodies of water cannot be supplied, thus creating heat islands. A heat island is defined as a phenomenon in which, due to urbanization, the air temperature in urban areas is considerably higher than in the countryside (Yao et al., 2017). This inevitable product of urban development has a prominent impact on air temperature and pollution, affecting the quality of life and well-being of its inhabitants and worsening the climate of the region.

Due to the negative effects that UHIs have on the environment and on human health, it is hypothesized that the thermal effect resulting from urbanization and industrial activity is diminished by the presence of green/blue infrastructure (GBI), and that its patterns distribution and behavior can be analyzed, evaluated and monitored by applying remote Earth observation sensors.
This study aims to demonstrate the relationship between land surface temperature (LST) and GBI, and how it is linked to the urban development of the Monterrey Metropolitan Area during the last 20 years. By obtaining the LST of the study area for the years 2003, 2013 and 2021 and identifying the conditions of the green/blue infrastructure, it was possible to analyze how the urbanization decreases the cooling effect of the MMA's urban rivers and green areas.

1.1 Background

In recent decades, the disorderly growth of urbanization and industry has generated degrading processes that alter the earth's surface and, therefore, the natural state of basins and rivers are also affected (Castro-López et al., 2019; Everard & Moggridge, 2012). The UHI effect has become a significant problem in cities. Poor urban planning and management cause vegetated areas to be replaced by impermeable surfaces such as concrete and asphalt, thus altering morphology and resulting in increased local temperatures and longwave radiation and temperature (Jiang et al, 2021).

Monitoring the urban thermal environment can provide important information about urban thermal structures. Studies carried out in the United Kingdom found that green and blue infrastructure improves surface porosity and increases water storage capacity. Therefore, water bodies such as rivers and lakes have the potential to reduce UHI and return levels of humidity to values similar to those of rural areas (Hathway, E.A., Sharples, S., 2012).

Identifying the urban heat islands of the MMA is necessary to quantify their growth and relationship with the urbanization and industrialization processes. The increase in temperatures in the city makes housing more expensive, causing family stress that can lead to domestic violence. Corral-Verdugo et al., 2014, have documented these conditions of social impact. Low-income neighborhoods are exposed to higher land surface temperatures (Chakraborty et al., 2020). It is estimated that mortality rates in the MMA have an increase of 19% for every 1°C increase in temperatures above 31°C (Wolf & McGregor, 2013).

The need to cool homes when high temperatures occur by using air conditioning represents an economic impact for the population and translates into a strong environmental impact due to greenhouse gas emissions such as the CO2. Urban land cover transformations are another factor that produces anthropogenic heat emissions to the atmosphere, thus contributing to UHI (Mohan et al., 2020).

Higher temperatures are characteristic of the city center under calm wind conditions and decrease with distance towards suburban, rural and wild areas (Raj, S et al., 2020). If intensity and magnitude vary according to regional climatic conditions and the characteristics of the buildings -albedo, emissivity, sky view factor, anthropogenic heat fluxes- (Jauregui, E. et al., 1992; Taha, H.et al., 2018).

The use of remote sensing techniques to study variations in urban heat island phenomena between different types of coverage is important for the precise monitoring of UHIs and for the objective identification of the spatiotemporal fields they present (Xu, D. & Zhou, D. 2016).

2. Methodology

2.1 Study area

Nuevo León is part of hydrological region number 24 (RH24) Bravo-Conchos, located in the north of the country, whose main channel and the border between the United States and the United Mexican States is the Bravo River. In the RH24 Bravo-Conchos, there are problems of water shortage in the areas with greater economic and demographic development. The Monterrey Metropolitan Area is characterized by three urban rivers that cross it: Santa Catarina, La Silla and Pesquería rivers are sub-tributaries and tributaries of the San Juan River of the Bajo Bravo subregion that belongs to the RH24, whose basin has become the second most polluted in the country (Scheteingart, M., D'Andrea, L. & García Ortega, R., 2001).

The Pesquería River rises in the municipality of García, Nuevo León and crosses the municipalities of García, Monterrey, Escobedo, Apodaca and Pesquería. The streams that make up this river originate in the protected natural area of Cumbres de Monterrey and the Sierra El Fraile and San Miguel, belonging to the hydrological-administrative region of the Río Bravo (Ferriño, 2015).

The Santa Catarina River rises in the San José Mountains, near the limits of Coahuila and crosses the municipalities of Santiago, Santa Catarina, San Pedro, Monterrey, Guadalupe, Juárez and Cadereyta, having an approximate extension of 60 linear km. It is considered a State Protected Natural Area that, despite having an intermittent channel, has riparian vegetation that develops along the course of natural waters (Naturalista México, n.d.).

On the other hand, the La Silla River originates in the Huajuco area in the foothills of the Sierra Madre Oriental, is part of the hydrological-administrative region of the Río Bravo in the Río Bravo-San Juan basin and runs through a portion of two subbasins, the El Pinito-Los Angelitos subbasin and Alto Santa Catarina 1. It has an approximate extension of 40 linear km and 7.44 km belong to the Protected Natural Area (ANP for its initials in Spanish) Nuevo La Pastora Ecological Park (Gobierno Municipal de Guadalupe, 2020). (Figure 1)

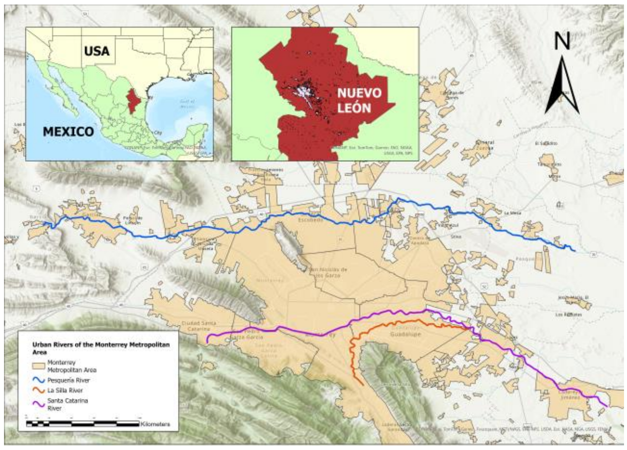

Figure 1. Study area location, Monterrey Metropolitan Area

2.2 WUDAPT LCZ Generator

WUDAPT LCZ is a global protocol developed by Stewart and Oke to obtain information about the form and function of cities (Cai et al., 2018). It is comprised of 17 zones based on surface properties – height and density of buildings and trees – and surface cover – permeable or impermeable. (Figure 2 Sida et al. 2021).

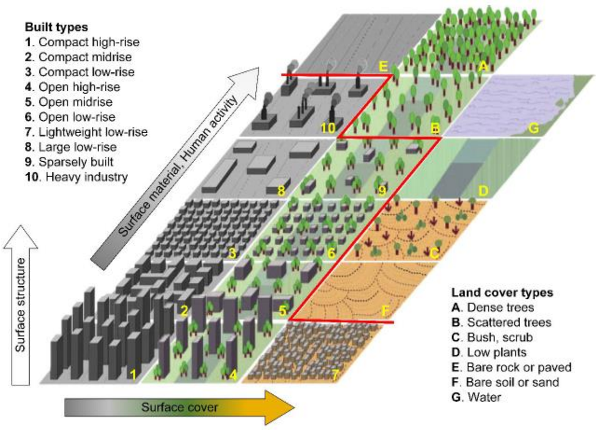

Figure 2. The 17 standand LCZs. Modified from Stewart & Oke (2012) by Sida, et al. (2021).

The categorization of the study area into LCZ types was accomplished by creating training areas in Google Earth and analyzing them in the WUDAPT web portal. These polygons provide a basic description of the local climate zones present (Mills et al., 2015).

For this case study, the classification of the MMA and the municipalities closest to it was performed, emphasizing the areas near the urban riverbeds -Santa Catarina, La Silla and Pesquería-. Therefore, the training areas corresponds to the infrastructure located in the municipalities of Apodaca, Cadereyta Jiménez, El Carmen, García, San Pedro Garza García, General Escobedo, General Zuazua, Guadalupe, Juarez, Marín, Monterrey, Pesquería, Salinas Victoria, San Nicolás de los Garza, Santa Catarina and Santiago.

2.3 Google Earth Engine (GEE)

To obtain the land surface temperatures for the proposed study years, the Google Earth Engine (GEE) platform was used, which allows complex analyzes of geospatial information

(Perilla & Mas, 2020). For this case study, the *LST mean composite over Monterrey Metropolitan Area* script was used, originally found at https://code.earthengine.google.com/6f3cf77c1a23599b92857e4eaa852ad9, and which F. Yépez later modified in November 2022.

This script obtains the LST and random points of a designated area with Landsat 8 images. For the evaluation of the LST of the study years; the minimum, maximum and average temperatures recorded by the stations of the Nuevo León Sistema Integral de Monitoreo Ambiental were analyzed and the hottest periods were determined according to the maximum monthly temperatures; thus obtaining the months of May, June, July and August as the sampling period.

Since Landsat 8 has collected information since 2013, modifications were made to the satellite image collection for the year 2003, which was evaluated with images from Landsat 5

3. Results

3.1 Local Climate Zones (LCZ) Classification

In the results obtained for 2003, it was found that the most representative LCZ types of buildings are compact and low-rise constructions, while areas with dense or dispersed vegetation are the predominant covers. This means that more type 3, A and B areas were found. (Figure 3).

By 2013 there was an increase in large and low-rise buildings as well as industries (classes 8 and 10 respectively). In the case of natural cover types, as in 2003, areas with dense vegetation or scattered trees were found to a greater extent (classes A and B). Additionally, there was a considerable increase in blue infrastructure, which is classified as type G training areas.

For 2021, polygons of all types of LCZ were found, with classes 3, 8 and 9 being the most representative in the case of construction types. On the other hand, the land covers with the greatest presence are classes B, D and G; This means that low-rise compact constructions and large, low-rise buildings predominate along with areas with scattered trees or low-rise vegetation.

When comparing the results obtained, although compact and low constructions predominate in all cases, there was a considerable increase in large low-rise buildings and heavy industries over the years, not to mention that the areas densely populated by trees, decreased considerably, or were replaced by low vegetation, shrubs and bushes or by patches of soil without vegetation present.

General accuracies (Overall accuracy; OA) of between 0.41 to 0.43 were obtained, while the general accuracies of the urban local climatic zones (Overall accuracy for the urban LCZ classes only; OAu) were 0.49 for the results of 2003, 0.54 for 2013 and 0.55 for 2021. In the case of the overall accuracy for the built versus natural LCZ classes only (OAbu) and the weighted accuracy (OAw), there was no considerable difference between the years of study, since the results are in ranges of 0.76 to 0.85 and 0.83 to 0.87 respectively.

The values obtained in the general precisions are governed by the Kappa index (k), which evaluates the agreement or reproducibility of instruments by representing the proportion of agreements observed beyond chance with respect to the maximum possible agreement beyond chance (Abraira, 2001).

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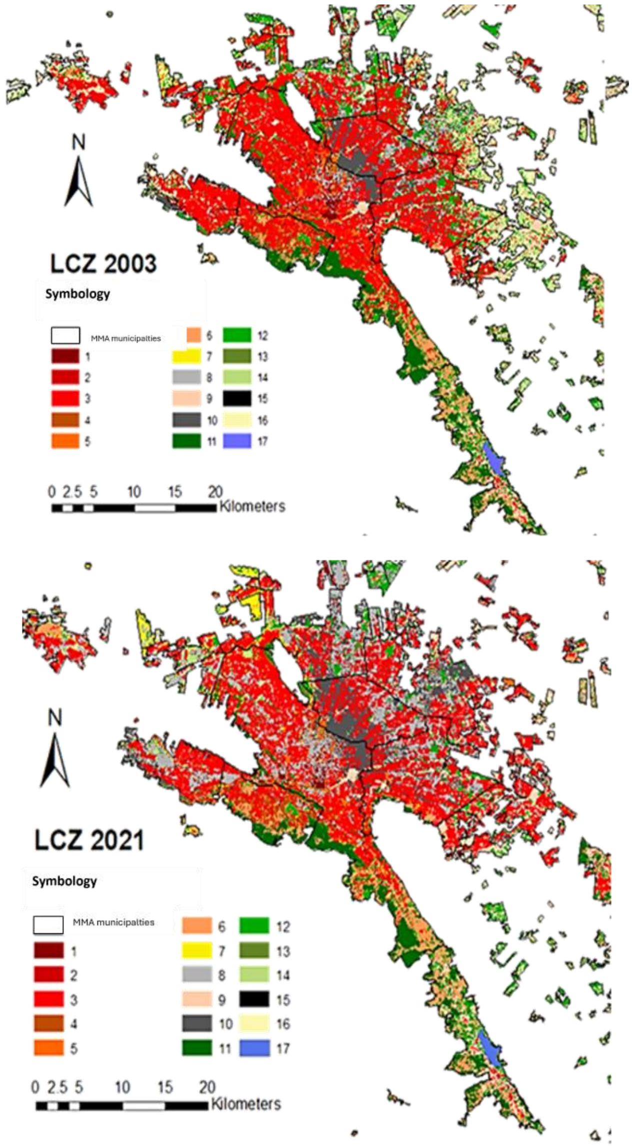

Figure 3. Local climate zones in the Monterrey Metropolitan Area 2003 and 2021.

3.2 Land Surface Temperature (LST)

The LST of the Metropolitan Area was evaluated using Google Earth Engine for the months of May to August 2003, 2013 and 2021. This period corresponds to the hottest days reported by the State's Sistema Integral de Monitoreo Ambiental, reaching temperatures above 30°C.

Similar LST values were obtained for 2003 and 2021. In both cases, the land surface temperature reached 43°C and a minimum of 19.6°C was recorded. The GBI present in the MMA presents lower temperatures compared to the urbanized and industrial zones, which registered the highest LST values.

Of the 3 years of study, 2013 recorded the highest temperatures amongst the three years analyzed, having a maximum LST of 44°C. As in 2003 and 2021, the urban and industrial areas show higher LST values compared to the GBI areas, which recorded minimum LST values of 17°C (Figure 4).

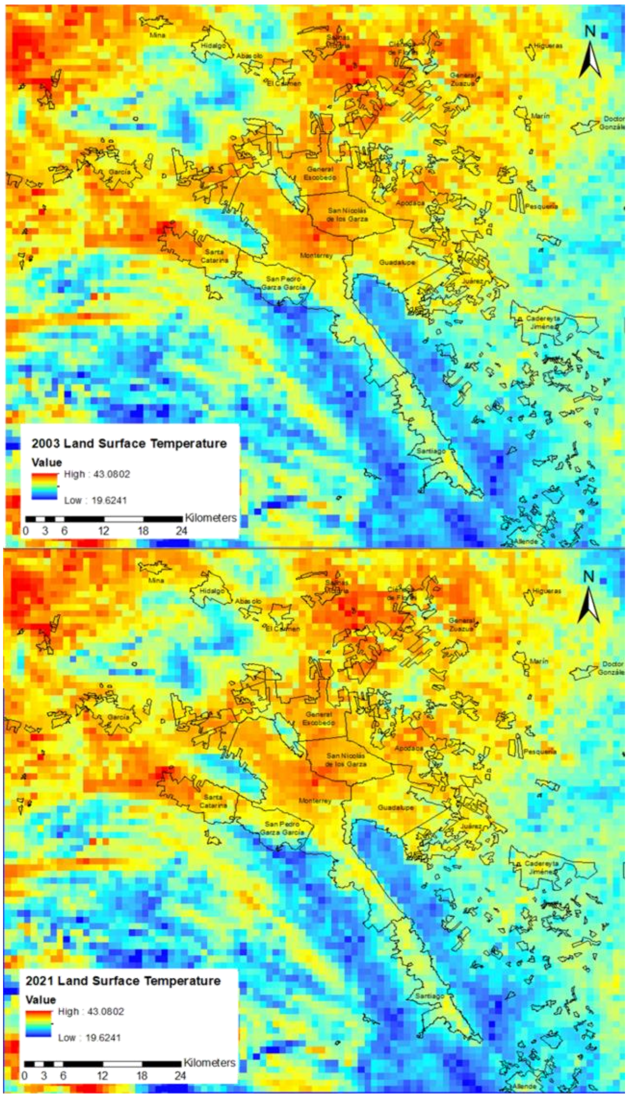

Figure 4. Land surface temperatures in the Monterrey Metropolitan Area 2003 and 2021.

3.3 LCZ and LST relationship

800 points were obtained, of which 755 were analyzed since these are located within the area of the LST and LCZ raster generated with WUDAPT LCZ Generator respectively. The points obtained were used for the 3 years of study, thus obtaining the average temperatures for each local climatic zone in a range between 19.62°C and 43°C. (Table 1).

Comparing the results obtained, it is observed that there is no considerable variation between the 3 years of study and that the dog days period of 2013 was the hottest with temperatures above 30°C in most of the local climate zones. In general, it can be seen that the temperatures recorded for the built areas are higher than those for the surface cover climate zones with a difference of around 4°C. (Figure 5).

Table 1. Average temperatures of local climatic zones

LCZ	Average temperature (°C)		
	2003	2013	2021
1	36.95	37.75	36.95
2	N/A	N/A	35.16
3	34.72	35.39	34.69
4	34.97	37.00	34.97
5	34.98	35.60	35.84
6	31.62	32.11	32.01
7	34.29	37.64	34.81
8	36.37	37.36	35.66
9	32.33	33.85	32.99
10	35.37	37.13	35.28
A	29.02	28.54	29.06
B	32.68	33.06	31.87
C	32.44	36.18	33.99
D	32.22	33.94	32.56
E	29.19	34.55	30.46
F	35.49	37.34	31.36
G	28.05	30.61	28.05

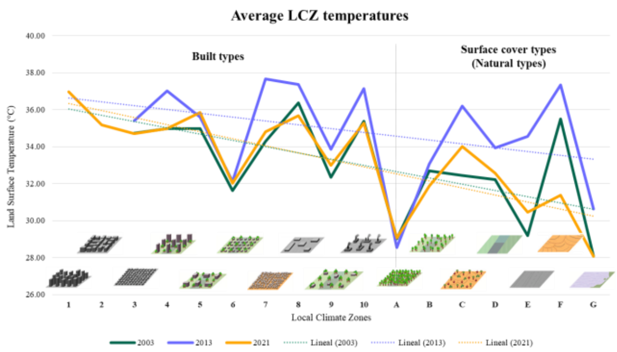

Figure 5. Comparison of average LCZ temperatures.

The land surface temperatures recorded at random points for the three years of study were evaluated and it was found that the intensity of the temperature varies depending on the type of land use. By dividing the classes proposed in the WUDAPT methodology into three subgroups (green/blue infrastructure, natural covers and built types), an alternation can be seen between green/blue infrastructure and natural covers that present little or no vegetation even when both subgroups are categorized. as surface cover types within the WUDAPT classification.

For the new subgroups, classes 1 to 10 are considered as built, classes A, B and G as green/blue infrastructure and classes C, D, E and F as natural covers. It can be distinguished that for the three years of study the temperatures recorded for the natural covers present greater agreement with the temperatures of the built areas. (Figure 6).

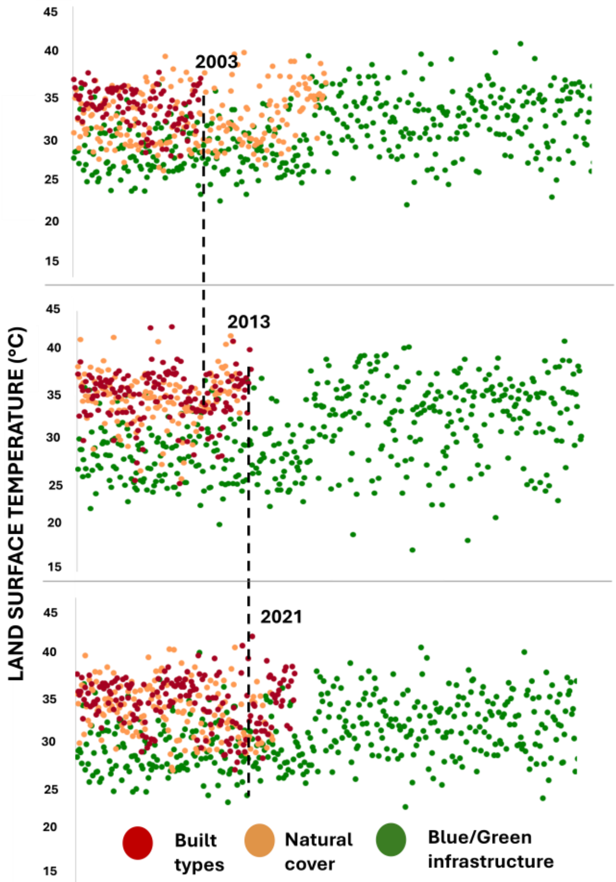

Figure 6. Land surface temperature of anthropic and natural classes random points.

4. Discussion

The question of whether the thermal effect of urban heat islands is reduced by the presence of green/blue infrastructure is answered positively. This is because the results indicate that surface cover LCZ, emphasizing areas with dense GBI, have lower temperatures compared to build areas.

Creating sufficient training areas that fit the description of the form and functions of the local climate zone that they represent is essential to obtain timely results. According to Mills et al., 2015, this is necessary to obtain higher quality images that accurately describe the study area. In the analysis, moderate results were obtained for the OA and OAu precisions of the three years of study, and substantial or almost perfect results for the OAbu and OAw according to the Kappa index.

The relationship between land surface temperature and GBI is described in various studies. Cai et al., 2018 mention that LST obtained from satellite images can be used to establish the link with local climate zones. On the other hand, Sun et al., 2012 points out that it is common to evaluate the effect of heat islands through surface temperature, since it can be easily extracted through remote sensing. When evaluating the land use images generated with the thermal images of the three years of study, the connection between the LCZ and the surface temperature of the soil is observed, since there is a difference of 4°C between the temperatures of the built LCZ and the surface cover climate zones. Furthermore, it is observed that the temperatures recorded in the GBI subgroup are lower, corroborating its cooling effect.

Some results in the literature point to the cooling and environmentally friendly effect of green/blue infrastructure as a solution to rising temperatures in densely populated urban areas. Emphasizing blue spaces, Lin et al., 2020 indicate that in addition to aiding in temperature reduction, the creation, maintenance and remodeling of these spaces reduce health risks to citizens. Although their effect may vary due to factors such as climate and wind, water resources are key to UHI mitigation and can be considered as cold urban islands according to Nakayama and Hashimoto, 2011.

5. Conclusions

This project aimed to demonstrate the relationship between land surface temperature and green/blue infrastructure and how it is linked to the thermal effect of urban heat islands through the analysis of satellite images. This premise was addressed according to the GBI definition of Jiang et al 2021, which is why the results of the green areas and urban rivers of the Monterrey Metropolitan Area stand out.

Regarding the limitations of this research, the general accuracy of the images of local climate zones was moderate for the three years of study. The refinement of the training areas and the land surface temperature images will provide results that are more exact.

From the results obtained, it is concluded that built classes – compact low-rise and industrial buildings mostly – have replaced 15.64% of the natural areas of the MMA during the study period. The assessment carried out indicates that the constructed LCZ have temperatures 4°C higher compared to the natural ones. Furthermore, there is a variation between areas with dense green/blue infrastructure and natural covers with little or no vegetation, the former being those that have a more intense cooling effect as they present lower temperatures. This proves that there is a relationship between local climate zones (LCZ) and soil surface temperature (LST).

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