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Urias Barrera, Hiram Eduardo; García Cueto, Onofre Rafael; Bojórquez Morales, Gonzalo
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Identification and classification of local climate zones in a semi-arid city of northwestern Mexico

Identi icación y clasi icación de zonas climáticas locales en una ciudad semiárida del noroeste de México

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HIRAM EDUARDO URIAS BARRERA
https://orcid.org/0000-0003-0809-8842 / a183783@uabc.edu.mx.

ONOFRE RAFAEL GARCÍA CUETO
https://orcid.org/0000-0003-4594-2600 / rafaelcueto@uabc.edu.mx.

GONZALO BOJÓRQUEZ MORALES
https://orcid.org/0000-0001-9303-9278 / gonzalobojorquez@uabc.edu.mx.

Universidad Autónoma de Baja California, México.

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ABSTRACT

Most cities located in developing countries have expanded in a disproportionate and irregular manner, which favors the formation of areas with different characteristics called Local Climate Zones (LCZ), which promote the increase of intra-urban temperatures and the formation of the Heat Islands (HI). In semi-arid regions there are few researches that have conducted LCZ studies and its relation with the HI phenomenon. This study's purpose was to carry out this classification and its relation with the increase in temperatures in the city of Mexicali, Mexico. Visual *in-situ* surveys, analysis by Geographic Information Systems (ArcMap and Idrisi), a categorization based on Stewart and Oke's work (2012) and a comparison with the city´s thermal images were carried out to determine the relationship of the urban structure and the HI. The results can have an impact on urban planning, serve as a reference for authorities so they can establish critical points and develop policies that help reduce the population's mortality and morbidity. The results can also serve as a basis for designers that develop strategies that seek surface temperatures decrease; on the other hand, it is imperative to point out that the works of Stewart and Oke (2012) cannot be fully replicated and its application had to adjust to the city's conditions.

Keywords: local climate zones, urban, classification

RESUMEN

La mayoría de las ciudades ubicadas en países en vías de desarrollo se han expandido de manera desproporcionada e irregular, lo que favorece la formación de áreas con diferentes características denominadas zonas climáticas locales (ZCL), que promueven el aumento de las temperaturas intraurbanas y la formación de las islas de calor (HI). En las regiones semiáridas existen pocas investigaciones que hayan realizado estudios de

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ZCL y su relación con el fenómeno HI. El propósito de este estudio fue realizar esta clasificación y su relación con el aumento de temperatura en la ciudad de Mexicali, México. Se realizaron levantamientos visuales *in situ*, análisis por sistemas de información geográfica (ArcMap e Idrisi), una categorización basada en el trabajo de Stewart y Oke (2012), y una comparación con las imágenes térmicas de la ciudad para determinar la relación de la estructura urbana y la HI. Los resultados pueden tener un impacto en la planificación urbana, servir de referencia a las autoridades para que puedan establecer puntos críticos y desarrollar políticas que ayuden a reducir la mortalidad y la morbilidad de la población. Los resultados también pueden servir de base para los diseñadores que desarrollan estrategias que buscan la disminución de las temperaturas superficiales; por otro lado, es imperativo señalar que los trabajos de Stewart y Oke (2012) no pueden ser replicados en su totalidad, y su aplicación tuvo que ajustarse a las condiciones de la ciudad.

Palabras clave: zonas climáticas locales, urbano, clasificación

INTRODUCTION

Urban heat island (UHI) development is the best example we have of local climate changes that take place in the cities (Lehnert *et al.,* 2015). A heat island refers to a microclimatic phenomenon that occurs in urban environments. It consists of an increase in temperature inside urban areas, which therefore are warmer than their rural surroundings (Hawkins *et al.,* 2004). Usually the difference in temperature is more noticeable during the night than in the day, and it is best manifested when the winds are calmer (Oke, 1982; Lauriola, 2016).

At a seasonal level, the UHI phenomenon occurs during both the winter and the summer Amirtham *et al.,* 2009); it is more severe for the urban dweller during the summer because the heat waves intensify the UHI (Leconte *et al.,* 2015); therefore, within the cities the UHI threat to human health must be carefully approached.

In semi-arid regions the higher temperatures during the summer strongly affect the quality of life in the cities, producing negative impacts that can be summarized as a noteworthy deterioration in bioclimatic comfort, as well as an increase in energy consumption, due to the use of air conditioning, which in turn, determine a greater emission of air pollutants and greenhouse gases (Thomas *et al.*, 2014; Villadiego & Dabat, 2014). These aspects cause the cities to be continuously vulnerable to climate change; and although the UHI phenomenon is not a direct consequence of climate change, it is expected to exacerbate during the second half of the century when the global average temperature is very likely to increase due to the warming predicted by climate models (Lelovics *et al.,* 2014).

There are several reasons why the UHI phenomenon occurs in urban areas. The main cause is related to the physical characteristics of the materials of urban surfaces (mostly concrete and asphalt) which absorb incoming solar radiation, and do not reflect it in the same proportion, so the extra heating of the surfaces determines the emission of a large amount of long-wave radiation, especially at night (Messias & Martins, 2016; Gaffin *et al.*, 2008). Another factor related to the increase in temperatures is the heat released due to the consumption of energy (heating and air conditioning, industrial activities, transport, etcetera), which is mostly concentrated in urban areas.

Traditionally, the urban heat island has been defined as the thermal difference between the city and its immediate surroundings, however, according to Romero *et al.,* (2010) cities present a heterogeneous spatial context that are the product of the different land uses and coverages, propitiating differences in temperature inside the cities, whose origin is due to the different physical and thermal characteristics of the urban materials (Stewart & Oke, 2012; Verdonck *et al.,* 2017). Due to the above, it is not easy to perform a comparative evaluation of UHI studies without taking into account the characteristic elements and forms that compose the cities (Coseo & Larsen, 2014). Stewart and Oke (2012) proposed a classification scheme of Local Climate Zones (LCZ) to facilitate the inner comparison of magnitudes and intensities of UHI in different cities of the world. Such scheme includes 17 classes based on surface coverage, structure, materials and human activity. Each class of LCZ describes a type of construction or a type of natural covering. It also takes into consideration the geometric, thermal, radiative and metabolic properties that make each type of LCZ different from the others (Alexander & Mills, 2014). Therefore, each LCZ provides a disjoint and complementary partition of the landscape that covers the main urban forms and land cover types (Stewart & Oke, 2012; Betchel *et al.,* 2015a, b).

Taking into account the urban morphological details and the ordering of the land uses, the integral approach of LCZ's classification has had a wide acceptance by urban climatology studies (Bentchel & Daneke, 2012; Müller *et al.,* 2013), which is why in recent years several studies have been conducted using this scheme to describe the city's thermal properties using information obtained from thermometric stations, instrumented vehicles, remotely sensed thermal images, land use and coverage data, and urban morphology information acquired from various sources (Siu & Hart, 2013; Peng & Jim, 2013; Puliafito *et al.,* 2013; Stewart *et al.,* 2014; Savic *et al.,* 2014; Emmanuel & Loconsole, 2015; Geletic & Lehnert, 2016; Perera *et al.,* 2018).

There are relatively few studies regarding the use of the LCZ scheme in cities located in arid zones (Georgescu *et al.,* 2011; Middel *et al.,* 2014; Fan *et al.,* 2017, Potchter *et al.,* 2008; Hao *et al.,* 2016; Wang *et al.,* 2018), despite the fact that in several of these cities there has been an accelerated increase in urbanization without urban planning. One of these cities is Mexicali, this study's subject matter, is located in the northwest of Mexico, where a urban heat island (García-Cueto *et al.,* 2007, 2009), and intra-urban differences (Casillas *et al.,* 2014) have been detected. In relation to the above mentioned, in this work the LCZ scheme concept is applied to Mexicali, Mexico, a semi-arid city of the Mexican desert, with the purpose of identifying and evaluating its applicability to an urban context very different from where the classification was originally conceived, which undoubtedly will serve as a guide to establish thermal monitoring sites in the immediate future.

STUDY AREA

The city of Mexicali is located in the extreme northeast of the state of Baja California and northwest of Mexico (figure 1); it is located at 32,65° N and 115.45° W. It has a varied orographic medium, in the western part it is flanked by Cerro el Centinela, which has a maximum elevation of 750 m and an area of 10 km²; to the southwest is Sierra Cucapah that has a height of approximately 1,000 m and an area of 364 km². The inactive Cerro Prieto volcano is located in the southern part of the city, at a distance of 15 km, and has an elevation of 260 m. To the east of the region there is an agricultural valley with approximately 200,000 hectares. The Colorado River is the main water supplier for the agricultural valley cultivation area and for urban uses. According to the climate classification of Köppen, modified by Garcia (1981), Mexicali's climate is type BW (h") hs (x") (e") that indicates a dry arid warm climate, with extreme thermal variability; its average annual temperature is 23.0°C and its rain regime is in the winter season.

During the warm period, there are average temperatures of 42.0°C and extreme maximums of 45.0°C, from May to September. The cold period is during the months of December, January and February, with average minimum temperatures of 9.0°C, with extreme minimums of 2.5°C. The average relative humidity is between 60%-65% and with extreme maximum humidity of up to 100% in September and October. The wind speed ranges from 0.10 m /s to 8.0 m/s with dominant frequencies of 27% coming from the northwest, followed by, in order of importance, those of the southeast (24%), southwest (22%) and west (19%). Solar radiation has an average

FIGURE 1

Study area, Mexicali, Baja California

Source: Authors own creation.

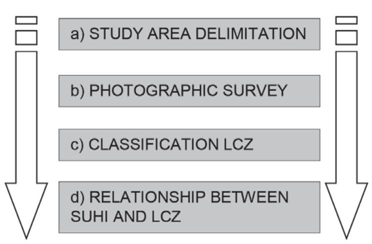
maximum of 937 W/m² in the summer period, and 345 W/m² in the winter. It is possible to have a maximum radiation of 1.205 W/m² in the warm period and a maximum daily average of 560 W/m² in the cold period (Luna, 2008).

DATA AND METHODS

For the development of this research, it was divided into three main parts that are linked to achieve the determined objectives: make a climatic classification of the city of Mexicali and the impact on the generation of the urban heat island; with which a methodology was established based on different works already cited (figure 2).

FIGURE 2

Methodology developed for research development



Source: Authors own creation.

First, the area to be analyzed was delimited through the information generated both by government institutions and previous bioclimatic diagnoses. Once this was done, a tour of the different sectors of the delimited area was proposed capturing a photographic survey of the characteristics of each one of them, which helped to determine typologies, peculiarities and features of each one of them. With this information, we proceeded to make a mapping of the urban area through the use of Geographic Information Systems software, establishing through the criteria of Stewart and Oke (2012) by establishing with this a general panorama the different local climatic zones to later extrapolate the information generated in the GIS (figure 4) and satellite images processed with information on surface temperatures (figure 5); With all this, the relationship between the UHI phenomenon and the different LCZs was determined.

A. STUDY AREA DELIMITATION

The 2025 Urban Development and Population Center Plan (UDPPC 2025), prepared by Mexicali's Instituto Municipal de Investigación y Planeación (IMIP, 2012) was analyzed. It includes the urban and sector restructuring plans (figure 3) and the land use plan, which were useful in order to make a first evaluation of the basic organization of the city. Based on the above, the perimeter on which the study would be carried out was established; an area of analysis was implemented with approximately 225 km^2, of which 56% is for residential use and the rest is divided between commercial areas, services, roads and urban reserve.

B. TOURS AND PHOTOGRAPHIC SURVEY

A route was established to cover the various sectors of the city previously fixed. After this, a Geographic Information System (GIS) was used, which optimized the trips within the study area; everything was supported with satellite images that helped a better categorization. It includes six routes, with four characteristics to take into account in order to carry them out, among which we highlight visiting housing neighborhood, industrial zones, service areas and agricultural areas or bare soils to reinforce the identification of the characteristics of each of them.

To plan the routes, criteria such as location of the area, concentration of economic activities and population were taken into account, as well as the age of the sector to be analyzed. The result of all this was a visual (photographic) survey, which will help to show particular and general characteristics of each one, which would also help to form a graphic synthesis of the real conditions of the urban area.

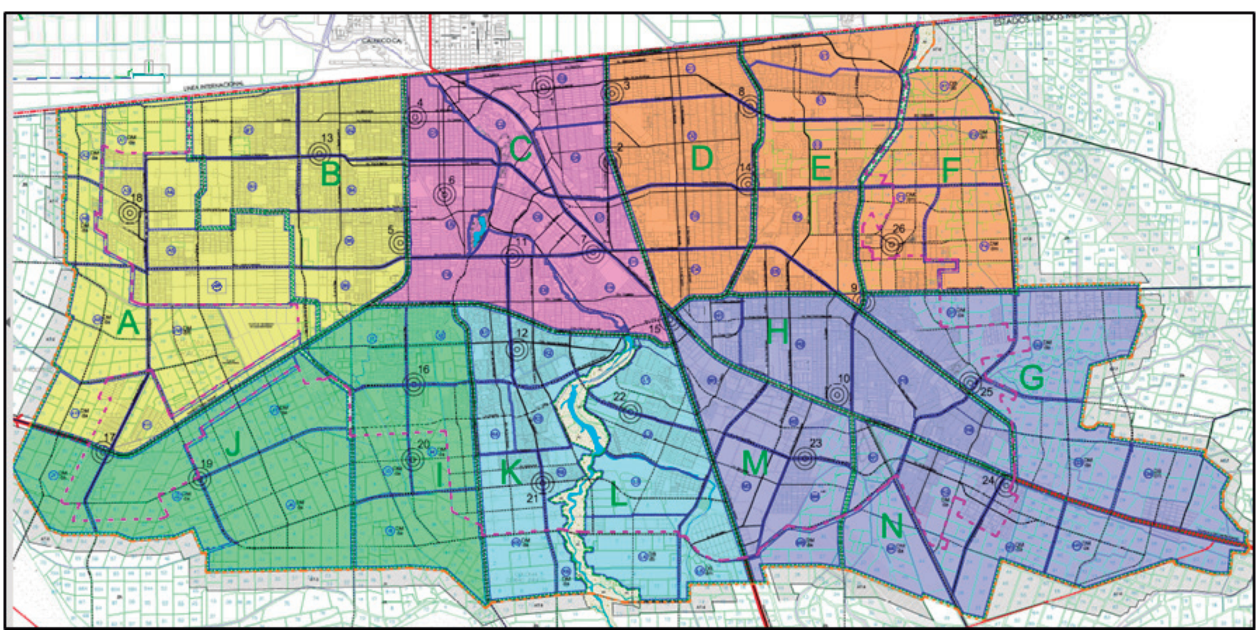
These excursions through the city took place in May 2016 and were a fundamental part of the classification, because it substantially complemented the decision making when establishing the comparative analysis of the LCZ proposed by Stewart and Oke (2012), and those found in this photograph catalog.

C. CLASSIFICATION FOR THE LCZ

The criteria to make the city's classification in LCZ were the particularities of the zones (coverage, surfaces, materials, physical structures and economic activities). These were identified on a

FIGURE 3

Urban sprawl limit of Mexicali



Note: The polygon's coordinates: 1. 32.62ºN, 115.55ºW; 2. 32.58ºN, 115.55ºW; 3. 32.58ºN, 115.37ºW; 4. 32.65ºN, 115.37ºW. Color code: Yellow = West Zone, Violet = Central Zone, Orange = East Zone, Green = Southwest Zone, Blue = South Zone, Purple = Southeast Zone.
Source: Based on IMIP (2012).

horizontal scale comprised of areas of no more than 1 km² (Stevan, 2013; Zheng, 2017; Chen & Ng, 2011), in which parameters, such as the percentage of buildings, building heights and their ground cover, were analyzed.

With a series of ordered and sequenced actions, a satellite image of the urban study area was examined; which corresponded to a GeoEye Ikonos file type with a resolution of up to 1 m² which suggests greater clarity of the RGB and NIR multispectral bands. ArcMap 10.2 software was used to analyze these images. This satellite image was of the month of January 2016.

For the characterization of the LCZ, study polygons were established in the completely urban area, whose dimensions were established in Stewart and Oke's (2012) work, where the measurements of these are determined between 100 m to 1500 m per side, since these distances depend on the type of homogeneity that the studied area presents. At this point, all the previously collected information was used, such as the photographic survey and the LCZ's property tables.

D. DETERMINE THE RELATIONSHIP BETWEEN SUPERFICIAL URBAN HEAT ISLAND AND LCZ

Satellite images were processed using Idrisi software version 17 to determine the urban heat islands. A satellite image of the Landsat project on the United States Geological Survey website (USGS. Available in: https://www.usgs.gov/) was selected, having a resolution of 30 m per pixel. In addition to the above, it was necessary that the image was L8 OLI / TIRS - Lansat 8 satellite image, taken with the Operational Land Imager (OLI) and Thermal Infrared Sensor (TIRS) instruments. The OLI sensor provides access to nine spectral bands that cover the spectrum from 0.433 µm to 1,390 µm, while TIRS registers two bands from 10.30 µm to 12.50 µm -. The image is from July24, 2016; this is within the 15 representative days where maximum temperatures are in the warm season between May and September, based on the bioclimatic diagnosis made for the region (Urias, Bojórquez, Garcia & Luna, 2016).

It was necessary to import all color bands B1 to B11 (B1, coastal-aerosols, B2 blue, B3 green, B4 red, B5 near infrared, B6 infrared short wave 1, B10 TIR 1, B11 TIR 2, B7 infrared short wave 2, B8 panchromatic and B9 cirrus) to process the file. Band 10, the infrared wavelength between 10.60 - 11.19 µm, was selected. It underwent a process within the IDRISI program to visualize the tem-perature variability, which consisted in adjusting the constants K1 and K2 to band 10, whose values were obtained from the MTL file that is included at the time of downloading the image; this analysis corresponds to the blackbody temperature that is derived from the B6 band, which corresponds to the surface temperature of the urban area.

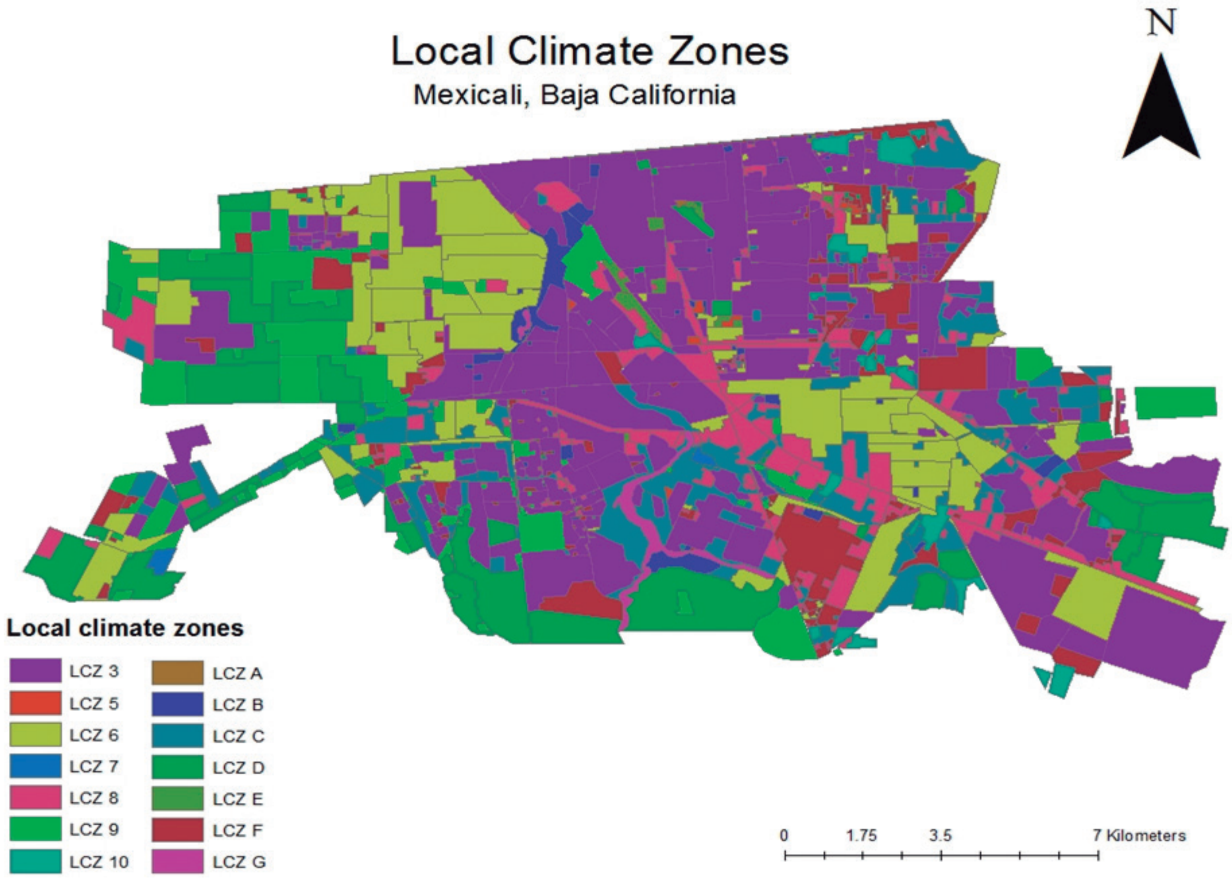
Later, the images processed to classify the LCZ, and the images used to identify the urban heat island, were contrasted. When performing a comparative analysis, the relationship between the different LCZ with the different magnitudes of the UHI was established. As a result, the LCZ and its classification, and for the particular case of the city of Mexicali, the characteristics that contribute to the magnification of urban temperatures were obtained.

RESULTS

The result of the local climate zones' classification was the existence of 13 out of the 21 established in Stewart and Oke's work (2012), whose characteristics, type coverage and land use, type and height of the constructions, and the construction density, helped its identification (tab. I). The LCZ identified in the city of Mexicali were the following: LZC-3, LZC-5, LCZ-6, LCZ-7, LCZ-8, LCZ-9, LCZ-10, LCZ-B, LCZ-C, LCZ- D, LCZ-E, LCZ F and LCZ G, which make up the general plan of the general LCZ's in the city (figure 4).

FIGURE 4

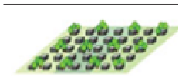
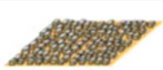
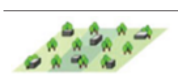
Local Climate Zones' Classification for Mexicali, Mexico



Source: Authors own creation.

TABLE I

Summary of Mexicali's LCZ and its occupation area in relation to the total percentage of the city

	Typology	Characteristics	Urban area (Km²)	Percentage
	LCZ 3	Low compact constructions	78.4757667	34.92%
	LCZ 5	Half open	0.41485774	0.18%
	LCZ 6	Open low, low density	37.7835763	16.81%
	LCZ 7	Light construction and low height	0.39682674	0.18%
	LCZ 8	Large construction and low height	16.7651101	7.46%
	LCZ 9	Sparse construction	18.8406358	8.38%

	Typology	Characteristics	Urban area (Km²)	Percentage
	LCZ 10	Heavy industry	3.55802482	1.58%
	LCZ B	Scattered trees	2.01617779	0.90%
	LCZ C	Bushes and shrubs	20.1576325	8.97%
	LCZ D	Low plants	28.0685768	12.49%
	LCZ E	Rock/gravel or pavement	1.00461848	0.45%
	LCZ F	Bare floor or san	15.7542686	7.01%
	LCZ G	Water	1.4954162	0.67%
		Total percentage	224.731489	100.00%

Source: Authors own creation based on Stewart and Oke, 2012.

The most prominent climate zones within the study area were LCZ 3, followed by LCZ 6, LCZ D, LCZ C, LCZ 9, LCZ 8 and LCZ F, then with much smaller extensions were LCZ 10, LCZ B, LCZ G, LCZ E, LCZ 5 and LCZ 7. The classification indicates that, in Mexicali, the zones with dense trees and scattered trees are null; there are only areas of low plants –farming fields and pastures, and fodder grasslands mixed in urban areas–, bushes and shrubs that correspond to land without buildings, mostly in the peripheral areas. The results (table I) were synthesized to establish the ratio of occupied urban area (km²) and percentage that represents the total of each of these zones within the city. LCZ which were found their description are below.

West zone: The predominant land uses in accordance with the UDPCP 2025 in this area are: popular housing, some urban reserve areas, urban facilities and services. It has seven different identified LCZ; it has large areas of bare soils and bushes, combined with agricultural areas –LCZ C–, coexisting with popular housing and social interest areas –LCZ 3–. In turn, the urban typology is changing as it approaches the urban center –LCZ 7–, since the constructions and the distribution of the constructions are transformed into average residential housing –LCZ 6– (figure 5a).

Central zone: It has heterogeneous land uses and typologies, where the historical part of the city, recreational, housing, commercial areas of services and equipment are found. The analysis carried out by the geographic information system showed that there are 11 types of LCZ. Through the trips and the photographic survey that was done, it was observed that in this sector there are trade-services and equipment –LCZ 8, LCZ 3–; The central zone has high and medium level residential neighborhood as it gets closer to the historical centre –LCZ –, with a percentage between 90 to 100% of paving in the area, – LCZ E – (figure 5b).

East zone: The prevailing land uses are housing types such as popular, medium and residential types. They have large concentrations of equipment, commerce and services (IMIP, 2012). Eight climate zones were located in the sector. The predominant uses of this area, supported by the photographic survey, is that of traditional popular housing – LCZ 6 –, up to the high-level

FIGURE 5

Photographic and satellite survey of the city of Mexicali (a) West Zone, (b) Central Zone, (c) East Zone, (d) Southwest Zone, (e) South Zone, (f) Southeast Zone

Source: Authors own creation.

residential housing –LCZ 8–. In addition, within the urban area limits, there are large vacant lots with bare floors and bushes – LCZ C –, farm plots – LCZ D -, which coexist within popular residential subdivisions – LCZ 3 –, industrial zones – LCZ 10 –, and scattered businesses (figure 5c).

Southwestern zone: The majority of the land is occupied by popular and of social interest type housing, areas of urban reserves, industrial zones and services. In this sector, there is a total of 8 LCZ located. A heterogeneity was observed; it has mostly housing developments of social and popular interest – LCZ 3 and LCZ 6 –, a minimum of commercial, industrial and warehouse areas – LCZ 8 and LCZ 9 –. There are large agricultural and grazing areas (cattle raising) – LCZ B, LCZ C and LCZ D – such as in the periphery of the urban area, which merge with the housing and industrial sectors within the city (figure 5d).

South zone: There are nine different climate zones contained in this sector. Verified by the tours made, this zone has lake areas and contains Mexicali's drains formed by the wastewater runoffs of the agricultural irrigations – LCZ G – and the country golf area, which is considered an urban green area - LCZ B –; In addition to the above, there are currently large areas of bare soils and shrubs – LCZ C –, agricultural areas – LCZ D – and to a lesser extent, industrial and commercial areas – LCZ 8 –. It was estimated that this sector is one of the sectors with the highest density of compact residential construction – LCZ 3 – (figure 5e).

Southeast area: Land uses in this area are popular and social interest housing type, industrial, services and equipment; The characterization result for this sector was a total of 7 different zones. A heterogeneity is distinguished during the photographic archive of the area was made. The union of agricultural fields – LCZ C – that were surrounded by housing complexes of social and popular interest – LCZ 3 – are observed. Besides this, there are large industrial areas and warehouses – LCZ 8 – which are already fully integrated into the existing urbanization. Since it is a section of the peripheral city, there is a considerable area of bare soil – LCZ F – and low shrubs – LCZ C and LCZ D –, and urbanized areas with both popular and social interest housing – LCZ 3 and LCZ 6 – (figure 5f).

LOCAL CLIMATE ZONES' RELATION WITH THE SURFACE URBAN HEAT ISLAND

When analyzing the relation between the LCZ and the Surface Urban Heat Island (SUHI), three zones with maximum temperatures were detected in the south, southeast and southwest parts of the city; whereas the most frequent LCZ are C, D, F, 3, 8, 9, 10. In addition, the effect that the green areas and bodies of water - LCZ B, LCZ C, LCZ G - have in the decrease in surface temperature was observed, while the observed temperature value can be up to 10° C lower, in relation to other areas.

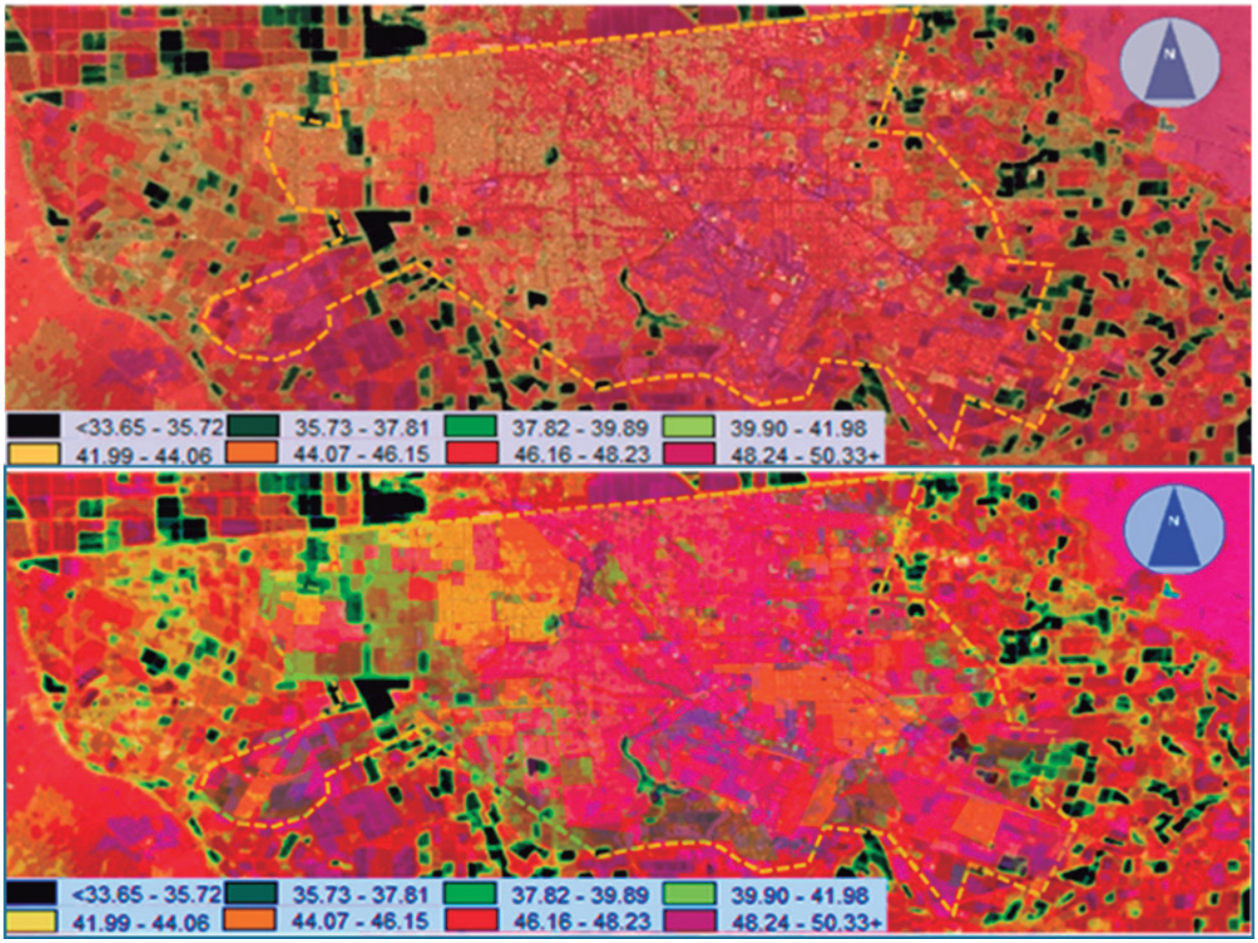
In the three identified areas, surface temperatures above 50.0 ° C were recorded. The one with the greatest urban extension was that of the south zone, followed by the city's east zone and spreading to the southeast. The third one is located in the southwest by agreeing with large sectors of low compact construction (LCZ 3) (figure 6). In some areas where there are a few trees, bodies of water and more dispersed residential areas with trees – LCZ 6, LCZ B, LCZ G – lower intensity SUHI are generated; one is in the western area that runs to the southwest and another in the downtown area of the city that spreads to the limit of the southern area, these were named medium intensity since the temperatures reach a maximum of 44° C.

It is observed that in the agricultural areas – LCZ D – bordering the city, the temperature can drop to 35.0° C; all of these generate a strip where the SUHI decreases drastically, which benefits the neighboring areas. In addition, by means of the thermal analysis, the routes for the photographic survey and the comparative analysis carried out for the climate classification, it was determined that in the sectors where there are exterior areas of bare soils – LCZ F –, abandoned lands – LCZ F and LCZ C – or scattered constructions – LCZ 8 –, the intensity of the surface heat island's effects increase up to 12.0° C.

Seven LCZ that most affect the SUHI were found (table II), due to their inherent characteristics and the percentage of city area they cover. When comparing the LCZs located in the sectors where the temperatures reached the highest record, they had areas with very dense and low-rise constructions - LCZ 3 -, areas of warehouses and industries - LCZ 8 -, and bare soils or scrublands - LCZ C and LCZ F - in common.

FIGURE 6

Thermal images of surface temperatures and formation of the SUHI, superposition with the LCZ



Source: Authors own creation.

TABLE II

Surface Urban Heat Island's relation with the Local climate zones in the critical areas

Local climate zones in critical heat islands with temperatures greater than 48.25°C	Typology	Characteristic
	LCZ C	Shrubs and bushes
	LCZ D	Low plants
	LCZ F	Soil or sand
	LCZ 3	Low compact –housing-.
	LCZ 8	Low large –commercial-.
	LCZ 9	Scattered construction.
	LCZ 10	Heavy industry.

Source: Authors own creation based on Stewart and Oke (2012).

It is also important to indicate that the surface temperatures (Ts) and the maximum air temperatures (Ta) recorded are at different times; the thermal image used was taken at approximately 10:00 h, while the maximum value of Ta observed was approximately at 15:00 h (Urias *et al.*, 2015). On the other hand, the Ts max record is obtained at approximately 12:00 h due to the heat transfer processes in the environment, where a temperature differential of 4.0 to 6.0° C increase in surface temperature can exist in relation to the values of the image.

DISCUSSION

There were five p redominant LCZs i n t he c ity of Mexicali. The densely built low-rise (LCZL 3), represented mainly by land use of social interest, large paved areas and minimum vegetation indices. It is mainly distributed to the south, southeast and east of the city as a result of the housing policies developed by the government. The low density and low height in buildings climate zone (LCZ 6), are dispersed primarily in neighborhoods that were once populations that did not belong to Mexicali's urban area, but that due to their proximity and Mexicali's urban growth, they are now part of it. In comparison with the previous LCZ, it has a higher level of vegetation, and incidence of bare soils - wastelands-. Contrary to what was speculated, there is a significant incidence of areas of bare soil (LCZ F), shrubs and bushes (LCZ C), and low-lying agricultural areas (LCZ D) located mainly in the periphery of the city.

The heterogeneity in the urban composition of the city was confirmed, and this is accentuated as it approaches the peripheral limits of the urban sprawl; the excessive growth of this goes beyond the planning and the planned projects and has led to an amalgam of particularities that are accentuated and directly affect the temperature increases within the city.

This stimulates the formation of several heat islands with different temperature magnitudes, coinciding with precarious areas, with little or no urban planning; they are located in areas where the analysis showed low vegetation levels, higher percentages of bare soils, adjacent agricultural areas or within urbanizations; in these heat islands' the temperatures surpass 50.0º C; The difference between these sites and the city center and residential areas is mainly explained by an increase in the vegetation index, better urbanization plans and building density.

It is important to highlight that the tempera-tures in the image used are less than the maxi-mum of SUHI since the maximum value of this is recorded at 12:00 h (Casillas-Higuera and García-Cueto, 2019), which means that the intensity can reach an average of 5.0° C higher than the image used in this study. These temperatures can be dangerous for the population, since Jauregui (1995) and Jaramillo and Rodríguez's works (2011), mention that one of the main causes of the population's morbidity and mortality is the urban temperatures increase.

It was discovered that when applying Stewart and Oke's (2012) classification of Local Climate Zone, the aforementioned urban heterogeneity, didn't define a clear basis for classifying certain areas where there was a conjunction of two or more LCZ, in which there were a series of particularities that could define the studied area within more than one of the classifications established for LCZ.

The above was visualized mainly in the western, southwestern, southern and southeastern areas, where there are housing areas and agricultural-livestock remnants that cohabit together without a clear boundary or separation between them, in addition to large climate zones with features of bare soils and bushes with buildings scattered in large vacant areas; extensions of land destined for agriculture enclosed by large housing developments or industrial zones, with paved or poorly paved areas.

These found singularities favor the development of Local Climate Zones different from those established in previous works (Stevan *et al.*, 2013; Alexander *et al.,* 2014). The results can lead to the development of LCZ with peculiarities of temperature, constructions, urban structure and soil properties. Another urban particularity found is the isolated construction of popular housing (the product of self-construction) in the midst of large areas of bare soils or shrubs and bushes, which is a main characteristic for not being able to classify it within the established climate zones.

It was established that within the city of Mexicali, the application of the established LCZ can be used, but not entirely, due to the fact that the contexts with which Stewart and Oke's (2012) works were developed, for the urban climate classification are different. The particularities of the cities from which they were derived, have well regulated urban and regional plans, under regulations and laws that are applied in their entirety, a constant characteristic in most of the developed countries.

Just as the result obtained by Nduka and Abdulhamed (2011) in Nigeria, an emerging country with similar growth to that of Mexico, it was estimated that in Mexicali there are four hybridizations between different climate zones, which are not indicated in different research DOIng in other countries; This singularity indicate use of Local Climate Zones developed by Stewart and Oke (2012) is only applied partially in emerging countries, with hasty or excessive growth, where urban plans are not applied completely.

GENERAL CONCLUSIONS

- 13 different climate zones of the 17 established by Stewart and Oke (2012) were found, which can be observed in table I.
- It was observed that out of the 13 LCZ at least seven of them have a greater relation with the increase in surface temperatures, and of these, the bushes and shrubs areas – LCZ C –, bare soils and sand – LCZ F –, compact low-residential – LCZ 3 – and dispersed construction – LCZ 8 –, are more combined in the southwest, south, east and southeast, coinciding with the highest magnitudes of the SUHI.
- It was discovered that within the LCZs that had the most effect on the SUHI, there could be a value of up to 56.0° C, while in other areas of the urban sprawl where the vegetation indexes increased – LCZ B – or where there were bodies of water – LCZ G–, temperatures were recorded between 33.0 to 38.0° C.
- In Mexicali, there is no total paving. There are still large urban wastelands, areas with bare soils, constructions of low or medium height and a particular hybridization of various LCZ characteristics in small areas. These favor an increase in urban temperatures, which is clearly visualized when comparing the processed images of urban surface temperatures with the result of the developed climate classification.
- It was observed that the heterogeneity of the city and its unordered composition is a fundamental factor in the increase of urban temperatures in the most affected areas. The possibility of finding hybridization of different Local Climate Zones is always latent and you have to have the discernment to place the studied areas within the classification that best suits you; without leaving aside the possibility of adjustments and the approach of the development of new climate classifications to those already existing.
- The use of the classification of LCZ of the city of Mexicali, is a starting point to establish urban heat islands monitoring areas, with the purpose of improving its research and study.
- Finally, it is essential to confirm the methods used for climate classification in cities with characteristics similar to the one suggested in this study, to reinforce the area of knowledge on the subject and to reaffirm whether the application of the LCZ established by Stewart and Oke (2012) is the best for cities in emerging countries with urban areas where urban development plans are exceeded and reduced by the urban growth.

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