Does land-use affect the temperature distribution across the city of Tuxtla Gutiérrez, Chiapas, México?

¿El uso de suelo afecta la distribución de temperatura en la ciudad de Tuxtla Gutiérrez, Chiapas, México?

Itzel Castro-Mendoza,* José René Valdez-Lazalde,** Geoffrey Donovan,*** Tomás Martínez-Trinidad,** Francisca Ofelia Plascencia-Escalante,** Williams Vázquez-Morales****

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Abstract. A combination of natural (tropical latitudes) and human induced (Climate Change, Urban heat island) conditions give rise and exacerbate extreme hot temperatures, but mechanisms are unclear. Land use and land cover change (LULC) is considered one of the main causes of Urban Heat Island (UHI) but its contribution varies depending on local conditions. This study focuses on determining the influence of land use change on the UHI effect in Tuxtla Gutiérrez City by investigating the relationship between LULC and land surface temperature (LST). Through Landsat 5 and Landsat 8 imagery, this study analyzes historical LST. In 2017, the highest LST (>40 °C) occurred in the metal ceiling land class, which is made up of malls with open-air parking zones. This coverage occupied less than 3% of the total city area. Bare agriculture soil (BAS) class, located mainly on the periphery of the city, represented 11% of the city, and reported a mean LST of 35 °C, followed by asphalt roads with 34 °C and concrete ceiling with 32 °C. The lowest LST (< 28 °C), occurred in contiguous areas of trees greater than 3 ha. The LST variation when land use changed from trees to another coverage (1.3 to 3.1 °C) is higher than in the opposite direction (0.1 to 1.2 °C). The elimination or replacement of tress with impervious surfaces are the main causes for LST increase in Tuxtla Gutiérrez.

Keywords: Land use and land cover change, Land surface temperature, Urban heat island.

Resumen. La combinación de condiciones naturales (latitudes tropicales) y antropogénicas (Cambio Climático, Isla de Calor Urbana) inducen el incremento extremo de la temperatura; aunque los mecanismos no son claros. El cambio de uso de suelo es una de las principales causas de la Isla de Calor Urbana (ICU), aunque su intensidad depende de las condiciones locales. La investigación del medio ambiente en entornos urbanos es de relevancia, considerando que para el año 2030 el 60% de la población mundial se concentrará en ciudades y desde ahí enfrentará condiciones climáticas cada vez más extremas. Este estudio se centra en la relación del cambio de uso de suelo y la temperatura de

* Instituto Nacional de Investigaciones Forestales, Agrícolas y Pecuarias, Campo Experimental Centro Chiapas, Carretera Ocozocautla-Cintalapa km 3, 9140, Ocozocautla de Espinosa, Chiapas, México. ORCID: https://orcid.org/0000-0002-5356-9829. Email: castro.itzel@inifap.gob.mx. Autor de correspondencia.

** Colegio de Postgraduados, Campus Montecillo, Posgrado en Ciencias Forestales, Km. 36.5 Carretera México-Texcoco, 56230, Montecillo, Texcoco, Estado de México, México. Email: valdez@colpos.mx, tomtz@colpos.mx, fplascen@colpos.mx

*** USDA Forest Service, PNW Research Station, 620 SW Main, Suite 400 Portland, Estados Unidos de América. Email: geoffrey.donovan@usda.gov

**** Universidad de Ciencias y Artes de Chiapas, Programa de Gestión de Riesgos y Cambio Climático, Libramiento Norte Poniente No. 1150, edificio 21, Ciudad Universitaria, colonia Lajas Maciel, 29039, Tuxtla Gutiérrez, Chiapas, México. Email: williams.vazquez@unicach.mx
INTRODUCTION

Human activities change weather patterns at global and local scales (IPCC, 2018), causing cities experience consistently higher temperatures than surrounding rural areas (Oke, 1982; Howard, 1988; Eniolo et al., 2013). The Urban Heat Island (UHI) effect is mostly due to the surface changes and temperature differences between UHI and non-UHI areas. Due to the acceleration of climate change, and that 60% of the world’s population is expected to live in urban areas by 2030 (UN, 2018).

In Mexico, since 1990, urbanization has rapidly grown in tropical latitudes (Reyes and López, 2011). These trends of tropical urbanization and rising temperatures are seen in Tuxtla Gutiérrez (TGZ), which is the second most populated city of the Mexican tropics and home to 10% of the population of the state of Chiapas.

In the last three decades, temperatures in TGZ have risen in the dry season (De la Mora et al., 2016) and industrial development, traffic congestion, cloud cover, wind speed, precipitation, city geometry, and relative humidity. However, the main driver of UHI is land-use change (Li et al., 2018), a factor that explains about 70% of the total variance in land surface temperature (LST) (Oke, 1982). UHI intensity depends on the albedo and thermal inertia of construction materials, building density, aspect ratio, sky view factor (SVP), industrial development, traffic congestion, cloud cover, wind speed, precipitation, city geometry, and relative humidity. However, the main driver of UHI is land-use change (Li et al., 2018), a factor that explains about 70% of the total variance in land surface temperature (LST) (Oke, 1973; Indhoff et al., 2010)own or city (as measured by its population).

Recently, remote sensing data have helped UHI research by providing low-cost LST data at adequate temporal frequency (Sobrino et al., 2004; Amanollahi et al., 2016; Awan and Jovannovski, 2016) were methods to retrieve the land surface temperature (LST). Sensors such as MODIS (Moderate Resolution Imaging Spectroradiometer) and AVHRR (Advanced Very High Resolution Radiometer), offer thermal infrared information suitable for regional studies due to their spatial scale and spectral resolution (Mas, 2011; Amanollahi et al., 2016). Landsat imagery has been widely used at a finer scale for research (Zhao-Liang, Bo-Hui, 2013; Chen et al., 2017; Tan et al., 2017) and based on the relationship between land-use change and extreme temperatures in TGZ.

The purpose of the present study was to examine the relationship between land-use change and extreme temperatures in TGZ. Moreover, we tested three methods to retrieve the land surface temperature (LST) - Polarization Line Imager & Thermal Infrared Sensor (OLI & TIRS) - for land-use/land cover, geo-/biophysical and urban land use/land cover. Based on the cover types we defined three different viewing angles, to calibrate a simple model capable of characterizing the LST angular variability. The exercise is performed using MODIS Aqua and Terra. In absence of atmospheric information, researchers can use other methods for surface emissivity retrieval. The most common method is the Normalized Difference Vegetation Index threshold method, NDVI<sub>Th</sub> (Sobrino et al., 2008), which assigns an emissivity value to a given land coverage, bare soil or full vegetation, according to estimated NDVI values. However, NDVI<sub>Th</sub> has limitations; surfaces such as asphalt, or other common materials in urban environments, can cause inaccurate estimation of LST (Sobrino et al., 2008). A more accurate method than NDVI<sub>Th</sub> for urban areas is the Emissivity Classification Method (ECM), which assigns emissivity values to each land cover-land use class, based on the ASTER spectral library (ASL, https://spectral.jpl.nasa.gov/) reported by Sobrino et al., 2012.

In this research we examined the relationship between LULC and extreme temperatures in TGZ. First we estimated the surface UHI for the city of TGZ for three years (2001, 2011, and 2017) from historical analysis of air temperature. Later, we used Landsat 5 (TM) and 8 (OLI) imagery to define land use/land cover. Based on the cover types we retrieved LST by ECM method, as emissivity data were not available for the study area.

CHARACTERIZATION OF THE AREA

The city of Tuxtla Gutiérrez (TGZ) is the capital of Chiapas, a state located in southeastern Mexico.
co between 16° 48' 46" N, 93° 13' 12" O and 16° 40' 49" N, 93° 02' 19" O coordinates (Figure 1). Elevation ranges from 435 m to 917 m (Figure 1). The climate is warm and sub-humid with an average annual rainfall of 915 mm the majority of which falls in the summer (INEGI, 2017). The historical records registered 19 days with temperatures above 30 °C and 25.7 days of dry conditions per year with a mean annual temperature of 25.4°C. The hottest month is April with a mean maximum historical temperature of 45.5ºC. The city of TGZ occupies a valley surrounded on the south by Matamatzá Hill and on the east by The Sumidero Canyon National Park; both barriers hinder air flow and influence winds from the northwest with an average speed of 9.7 km/hr, reaching gusts during winter of 36 km/hr (Díaz-Nigenda et al., 2018).

The Sabinal River crosses the city through The Sumidero Canyon National Park to the Grijalva River. The predominant types of soil are Lithosols, Regosols, Luvisols and Vertisols. The city is surrounded by 4.9 km of Natural Protected and Conservation Areas of low deciduous forest (ICIPLAM, 2013). Almost 75% of the urban flora is exotic (Román, 2017) and distributed among 193 Conservation Areas of low deciduous forest (ICIPLAM, 2013) since vegetation competes with housing space.

MATERIALS AND METHODS

Data

We analyzed air temperature data from 11 weather stations (Figure 1) with a daily (1951-2016) and hourly (2013-2018) record. We used these data as reference to choose the capture date of the Landsat scenes downloaded and for the analysis of UHI in TGZ because weather stations are not evenly distributed across the city. Classification of LULC were validated in ground and with a high spatial resolution image (0.5 m) and a mosaic of orthophotos. Ground truthing of LST retrieved from Landsat images (Table I and II) was done at ten verification sites in 2019, May 29th and 30th using an Extech IR201A infrared thermometer with adjustable emissivity between 15:00 and 17:00 hrs. All images were processed on ArcMap 10.5 package.

Methodology

We were interested in the impact of extreme temperatures on human wellbeing and comfort. Therefore, we used vulnerability levels due to extreme air

Table I. Data used for land surface temperature (LST) retrieve at Tuxtla Gutiérrez City.

| Variable | Instrument | Source | Space scale | Time scale |
|----------|------------|--------|-------------|------------|
| Daily air temperature | Four weather stations | Weather National Service | N/A | 1951 to 2016 |
| Hourly air temperature | One weather station | Electricity Federal Commission | N/A | 2013 to 2016 |
| Land surface temperature | LandSat 5 scenes | US Geological Service [https://earthexplorer.usgs.gov/](https://earthexplorer.usgs.gov/) | 30 m | April 5, 2001 |
| Real color image of high resolution | Unknown | Ministry of Environment and Natural History in Chiapas (SEMAHN) | 0.5 m | 2015 |
| Mosaic of Panchromatic Image of high resolution | Unknown | National Institute of Statistics, Geography and Informatics (INEGI) | 1.5 m | 2001 |
| Surface temperature | Infrared thermometer | Extech brand model IR201A | N/A | May 29 and 30, 2019 |

Table II. Metadata of Landsat imagery.

| Satellite | Sensor | Pixel size (m) | Nubosity (%) | Date | Hour center of the scene |
|-----------|--------|---------------|--------------|------|-------------------------|
| Landsat 5 | TM     | 30            | 5%           | April 5, 2001 | 16: 15: 36.60295050Z |
| Landsat 5 | TM     | 30            | 6%           | April 1, 2011 | 16: 25: 30.5330810Z   |
| Landsat 8 | OLI_TIRS | 30          | 0.40%        | April 1, 2017 | 16: 35: 15.5568250Z   |

Figure 1. Location of weather stations in the city of Tuxtla Gutiérrez, Chiapas, Mexico.
temperatures defined by The Territory and Urban Development Ministry (SEDATU, 2014) as reference values when the analysis of results (Table III).

Most LST research has been done during the dry season because cloud cover is low and higher atmospheric humidity can increase the error of emissivity and temperature. For this reason, we confined our research to the dry season in TGZ.

To calculate LST, we applied conventional and thermal remote sensing corrections to the three scenes downloaded (Chander et al., 2009; USGS, 2013) Top-Of-Airmass (TOA). This correction was done in two stages. First, we considered the build-up of an emissivity layer according to the ECM, then, we retrieved LST by transforming thermal brightness (Figure 4). The combination of band thermal and radiometric correction (Figure 4), allowed to obtain LST values for each image.

Though atmospheric conditions are the main source of error for LST retrieval (Cook et al., 2014), we made no correction of this sort due to a lack of information on relative humidity, wind speed, and atmospheric pressure.

\[ LST = \frac{\text{ESUN} \cdot \cos \theta_i - T_{\text{emissivity}}}{\text{LMAX} - \text{LMIN}} \]

\[ \theta_i = \arcsin \left( \frac{1}{\text{LMAX}} \right) \]

\[ \text{LMAX} = \text{Spectral at-sensor radiance that is scaled to } Q_{\text{calmax}} \]
\[ \text{LMIN} = \text{Spectral at-sensor radiance that is scaled to } Q_{\text{calmin}} \]
\[ Q_{\text{calmin}} = \text{Minimum quantized value of pixel} \]
\[ Q_{\text{calmax}} = \text{Maximum quantized value of pixel} \]
\[ \text{ESUN} = \text{Mean exoatmospheric solar irradiance} \]
\[ \theta_i = \text{Solar zenith angle} \]
\[ d = \text{Source of error for LST retrieval} \]

Land use-land cover image classification

We radiometrically corrected each band of the images up to reflectance (Table IV) using equations 1 and 2 (Chander et al., 2009) Top-Of-Airmass (TOA). The correction served to sort the images, into nine LULC classes and thereby assign an emissivity value to each class.

\[ LST = \frac{\text{ESUN} \cdot \cos \theta_i - T_{\text{emissivity}}}{\text{LMAX} - \text{LMIN}} \]

Based on a high-resolution images and the orthophoto mosaic, we generated for each image classification training polygons consisting of nine classes of LULC (Table IV). These polygons were used to train a maximum likelihood algorithm (MAXLIKELIHOOD) and classify each image (Melesse et al., 2007; Sobrino et al., 2012).

The bare soil class denotes areas where the surface consists of bedrock (mainly limestone). The bare agriculture soil class denotes agriculture soil without vegetative cover. The rest of the classes are self-explanatory (Table V).

### Table III. Vegetation and human vulnerability due to extreme air temperatures.

| Temperatures | Vulnerability | Class |
|--------------|--------------|-------|
| < 28 °C      | Pleasant     | Comfortable wellness |
| 28 a 31 °C   | Discomfort   | Evapotranspiration increases. Headaches increase in humans. |
| 31.1 a 33 °C | Extreme discomfort | Dehydration is evident. Hoppers and heavy pollution particle pollution increases, appearing at cities. |
| 33.1 a 35 °C | Stress condition | Plants evapotranspire excessively and wilt. Forest fire hazard increases. |
| > 35 °C      | Upper tolerance limit | Heat strokes occur, with unconsciousness in some people. The diseases increase. |

### Table IV. Radiometric correction parameters for TM 5 and OLI 8 sensors.

| Band | QcMIN | QcMAX | LMAX | LMIN | d | ESUN | SZ |
|------|-------|-------|------|------|---|------|----|
| 2    | 255   | 1     | 365  | -2.84| 1.0005897|1796|31.31|
| 3    | 255   | 1     | 264  | -1.17| 1536|1031|
| 4    | 255   | 1     | 221  | -1.51| 1031|
| 2011 year |       |       |      |      |     |      |    |
| 2    | 255   | 1     | 365  | -2.84| 0.999269|1796|30.13|
| 3    | 255   | 1     | 264  | -1.17| 1536|1031|
| 4    | 255   | 1     | 221  | -1.51| 1031|

OLI 8 Sensor, 2017 year

| Band | QcMIN | QcMAX | LMAX | LMIN | d | ESUN | SZ |
|------|-------|-------|------|------|---|------|----|
| 3    | 0.011861 | -59.3059 | 0.00002 | -0.1 | 0.9994378|27.84|
| 4    | 0.0010002 | -50.0101 |     |      |     |      |    |
| 5    | 0.0001207 | -30.60357 |     |      |     |      |    |

\( Q_{\text{cmin}} = \text{Minimum quantized value of pixel} \) [dimensionless], \( Q_{\text{cmax}} = \text{Maximum quantized value of pixel} \) [dimensionless], \( L_{\text{max}} = \text{Spectral at-sensor radiance that is scaled to } Q_{\text{calmax}} \), \( L_{\text{min}} = \text{Spectral at-sensor radiance that is scaled to } Q_{\text{calmin}} \), \( \text{ESUN} = \text{Mean exoatmospheric solar irradiance} \) [W/(m2 μ m)], \( \theta_i = \text{Solar zenith angle} \) [degree] (Chander et al., 2009, USGS, 2013).
Table V. Emissivity values by type of sensor (TM 5 and OLI 8) and LULC classes.

| Sensor       | TM 5 | OLI 8 |
|--------------|------|-------|
| Band         | B6   | B10   |
| Range (μm)   | 10.4 ±12.5 | 10.6 ±11.19 |
| Water*       | 0.99 | 0.99  |
| Trees*       | 0.99 | 0.99  |
| Asphalt road*| 0.963 | 0.962 |
| Green grass* | 0.981 | 0.98  |
| Bare soil*   | 0.956 | 0.942 |
| Bare agriculture soil* | 0.968 | 0.941 |
| Concrete ceiling* | 0.957 | 0.943 |
| Metal ceiling* | 0.046 | 0.049 |
| Roof tile ceiling* | 0.942 | 0.939 |

* Source: Aster Spectral Library. +Source: (Sobrino et al., 2012)

Table VIII. Land use/land cover percentage across the city of Tuxtla Gutiérrez, Chiapas in 2001, 2011 and 2017.

| Class                  | Land coverage 2001 (%) | 2011 (%) | 2017 (%) |
|------------------------|------------------------|----------|----------|
| Water                  | 0.02                  | 0.01     | 0.02     |
| Trees                  | 17.63                 | 14.25    | 13.98    |
| Asphalt road           | 9.3                   | 13.22    | 12.95    |
| Green grass            | 1.8                   | 2.14     | 1.65     |
| Bare soil              | 2.67                  | 4.53     | 7.75     |
| Bare agriculture soil  | 34.77                 | 20.32    | 11.34    |
| Concrete ceiling       | 18.29                 | 28.98    | 35.54    |
| Metal ceiling          | 1.4                   | 2.85     | 2.6      |
| Roof tile ceiling      | 14.12                 | 13.71    | 14.16    |

Figure 3. Thermal hourly distribution registered at day and night in the city of Tuxtla Gutiérrez from years 2013 to 2018.

Figure 4. Average daily temperature and precipitation for the city of Tuxtla Gutiérrez, from 1951 to 2016 year.

Table VI. Thermal correction parameters to estimate the thermal brightness values.

| Sensor       | TM 5 | OLI 8 |
|--------------|------|-------|
| Band         |      |       |
| 6            | 607.76 | 1260.56 |
| 7            | 774.89 | 1321.08 |
|              | Sensor TIRS 8 |
|              |          |

TB is the thermal brightness [K]; TB_c is the thermal brightness in Celsius degrees [°C]; LST is the land surface temperature in Celsius degrees [°C]; K_1 is the first calibration constant [W/m² sr μm]; K_2 second calibration constant [K]; λ is the spectral radiance at-sensor [W/(m² sr μm)]; ln is natural logarithm; E is the emissivity; λ_c is the center of the thermal band [μm]; p is a constant that combines the Boltzmann and Plank’s Law and the speed of light with a value of 14,387.7 [μm/K°C] (Table VI).

RESULTS AND DISCUSSION

Daily air temperature data, from 1951 to 2016, showed that after 1980 temperatures above 40 °C have become more frequent by a rate of 18% and minimum air daily temperatures above 28 °C have increased by a rate of 14%.

Hourly records from 2013 to 2018 show that minimum daily temperatures occur between 14:10 and 17:00 hrs. Daytime temperatures, between 06:00 and 19:59 hrs, range from 8.6 °C to 48.4 °C. Nighttime temperatures, between 20:00 and 05:59 hrs, range from 9.2 °C to 32.5 °C. During the time scale study, 60% of daytime temperatures and 63% of nighttime temperatures occurred between 25 °C to 30 °C, suggesting that nights are as warmer as days in TGZ (Figure 3), but it is necessary to continue registering hourly air temperatures to confirm this trend.

As there are no weather stations located on the periphery of the city, we were unable to compare temperatures in the city center and the surrounding rural areas. In addition, there are no night Landsat images that record land surface temperature that would allow us to study diurnal variation in UHI.

Average daily temperatures for April and May, with average daily temperature of 27.2 and 25.0 °C, respectively. During these months, the maximum temperatures occur with clear skies and low relative humidity, ideal conditions for classification of LULC and LST retrieval (Figure 4).

This information was used to determine the Landsat scenes (Table II) in order to reach an optimum accuracy of the classification processes (Table VII).

The classification processed showed that tree coverage decreased by 21% in TGZ (Table VIII).
This loss of tree cover was concentrated along the Sabinal River, Botanical Garden, Zoo, some urban parks, and natural reserves areas on the south of the city (Figures 6 to 8).

The LST distribution for the three years of the study are given in Table IX and Figure 5. There are street trees in the area but quantifying their impact on temperature and surface
La clasificación BAS incluye tierras oscuras de arcilla consideradas isohipertermicas, termicas y alcalinas. Los suelos orientales tienden a tener temperaturas más altas que los de la misma clase en condiciones destructivas. El clima también influye en las temperaturas de los suelos; en zonas tropicales los suelos tienden a tener temperaturas más altas que las de las mismas clases en condiciones destructivas. La retención del calor en los suelos depende de su ubicación y de la actividad del día/noche (Jauregui, 2019; Imhoff et al., 2010; Ruddell y Dixon, 2014).

Areas with both, metal ceiling and asphalt roads, such as malls like Plaza de las Américas, Plaza Cristal and Plaza Poliforum showed thermal peaks (temperature above 40 °C). These results described are consistent with those reported by Coello (2015) who used a thermographic camera to retrieve temperatures for different coverages at the main campus of The University of Science and Art of Chiapas between 13:00 and 15:00 hrs. Coello reported that maximum temperatures occurred at the metal ceiling of sport courts (60.5 °C), followed by football camp with synthetic grass (55 to 59 °C), bare soil with the large range of temperature variation (46 to 58 °C), asphalt roads (52 to 57 °C), concrete (47 to 54 °C), scattered vegetation (33 to 38 °C) and swimming pool (28 to 29 °C) (Coello, 2015).
One transect profile was generated across TGZ from east to west direction to validate the changes in LST due to of land cover changes occurring from 2001 to 2017 (Figure 10). LST has increased due to transformation of trees into SDA or non-evaporating surfaces and decreased when land converted to trees (Table X).

The mean temperatures reported at Table X were those occurring at transect profile (Figure 10). The highest increase in LST occurred when trees became BAS (3 °C), followed by asphalt road (1.7 °C) and bare soil/concrete ceiling (1.4-1.3 °C). On the other hand, TGZ city had reforestation programs at median strips, parks and vacant lots in 2005 and 2016, and these programs appear to have a modest cooling effect (0.1 and 1.2 °C) by 2017 year.

On the 29th and 30th of May 2019 (Table XI) between 15:00:00 and 17:17:00 hrs, temperature verification performed in 10 sites across the city of TGZ. The sites were chosen considering the areas that reported high LST during 2017. May 29th presented sunny conditions, while May 30th was cloudy with drizzle. On both dates, the maximum temperatures were recorded on site 03, in the east of the city, which had BAS Leptosol with pebbly black earth. The second highest temperatures appeared on site 02, in the west, with BAS Vertisol and black soil with residual stubble. Synthetic pit grass was the second warmest coverage, followed by asphalt. Direct temperature measurement showed the same relative patterns, although there were some differences between directly measured and remotely sensed temperatures.

Table X. Land surface temperature (LST) variation in response to land use/land cover changes.

| Land use/land cover change | Area (ha) | Mean Temp. 2001 (°C) | Mean Temp. 2017 (°C) | Average change in LST 2001-2017 (°C) |
|----------------------------|-----------|----------------------|----------------------|-------------------------------------|
| Tree to asphalt road       | 30.33     | 32.27                | 33.99                | 1.7                                 |
| Tree to bare soil          | 21.69     | 32.27                | 33.64                | 1.4                                 |
| Tree to BAS                | 13.23     | 32.27                | 35.34                | 3.1                                 |
| Tree to concrete ceiling   | 64.7      | 32.27                | 33.6                 | 1.3                                 |
| Asphalt to tree            | 6.8       | 33.1                 | 32.9                 | -0.1                                |
| BAS to tree                | 20.5      | 35.6                 | 33.8                 | -1.2                                |

* BAS = bare agriculture soil.

Table XI. Land surface temperatures at verification sites.

| Site | Colony | Description | Latitude | Longitude | Temperature (°C) | Notes |
|------|--------|-------------|----------|-----------|------------------|-------|
| UNICACH, University City | Canteras Football field | 16.78 | -93.12 | 45.0 | 34.0 | Synthetic open pit grass |
| SEMAHN | Rivera Cerro Hueco Parking lot | 16.73 | -93.09 | 43.7 | 32.3 | Asphalt and stone |
| Market Dr. Rafael Pascacio Gambboa | El Calvario Market with metal ceiling | 16.75 | -93.12 | 45.0 | 34.7 | Area with high vehicular traffic and little vegetation cover |
| Plaza Del Sol (De las Américas) | Joyo Mayyu Parking lot | 16.76 | -93.14 | 40.8 | 35.3 | Asphalt |
| Terán airport Militar base air | Hill with bare soil vertisol | 16.74 | -93.18 | 43.8 | 34.1 | Costant burning for weed management, vertisol, black soil |
| Site 01 | Nameless Burned agricultural field | 16.77 | -93.20 | 42.5 | 33.8 | Bare regosol, brown soil |
| Site 02 | Nameless Agricultural field without stubble | 16.74 | -93.22 | 49.6 | 40.3 | Bare vertisol, black soil |
| Site 03 | Satellite (Loma Larga) Base soil | 16.74 | -93.05 | 50.7 | 48.0 | Bare leptosol, black soil, stony |
| UNICACH, Plastic Arts Campus | Tiocotumbak Football field | 16.75 | -93.10 | 41.0 | 37.1 | Synthetic open pit grass |
| Road | Road to Vicente Guerrero Asphalt | 16.74 | -93.21 | 46.8 | 36.8 | Asphalt road near vertisol soil fields |
Castro-Mendoza, Valdez-Lazalde, Geoffrey Donovan, et al.

Does land-use affect the temperature distribution across...

The approach implemented in this study to carry out the analysis could be used to evaluate the surface thermal dynamic of cities when monitoring weather networks are not available or are not wide enough to cover the study area properly.

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Kato, S., Koyama, T., Nakamura, R., Matsunaga, T., and Fukuhara, T. (2018). Simultaneous retrieval of other land use the LST increased at least 1 °C and decreased the same in the opposite direction. The minimum variation of LST detected in land use change from asphalt to tree (-0.1 °C) may be explained by the imagery resolution (30 m per pixel) and height of trees, since reforestation programs are recent, and according to Coello (2015), the refreshing effect of vegetation may be more than 10 °C in comparison with asphalt and BAS covers.

The cooling effect of vegetation in tropical cities may contribute to the wellbeing of the population by mitigating UHI, but more studies are needed in economic and social terms in each city for a strategy to determine the sites and area of reforestation, the maintenance work required, the best species for reforestation and the availability of soil and water needed.

CONCLUSIONS

For the city of TGZ, the materials with the highest thermal sensitivity were BAS and asphalt roads. The change of tree cover into asphalt road, bare soil or BAS cover caused LST increased 1 °C to 3 °C. When asphalt or BAS covers turned into the tree class, LST decreased from 0.1 °C to 1 °C, suggesting that the cooling effect of trees is not immediately reached after reforestation. The vegetable effect in LST is approximated if woodlands are greater than 3 ha indicating a limitation of the analysis caused by the spatial resolution of the imagery used.

The ECM for the thermal assessment captured the surface heterogeneity of the TGZ city avoiding underestimations induced for NDVI methodol-
gies. Nevertheless, the in-situ measures of emiss-
vity values and night temperature assessment will improve results and are desirable for further investigations.

The approach implemented in this study to carry out the analysis could be used to evaluate the surface thermal dynamic of cities when monitoring weather networks are not available or are not wide enough to cover the study area properly.

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