UNIVERSIDAD PERUANA UNIÓN

FACULTAD DE INGENIERÍA Y ARQUITECTURA

Escuela Profesional de Ingeniería Ambiental

Predicción de islas de calor urbano superficial en el Área Metropolitana de Trujillo (2017-2025) – Perú

Tesis para obtener el Título Profesional de Ingeniero Ambiental

Autor:

Aaron Jhonatan Huaman Santa Cruz

Asesor:

Dr. Alex Huaman De La Cruz

Lima, abril de 2022

DECLARACIÓN JURADA DE AUTORÍA DE TESIS

Dr. Alex Ruben Huaman De La Cruz, de la Facultad de Ingeniería Y arquitectura, Escuela Profesional de Ingeniería Ambiental, de la Universidad Peruana Unión.

DECLARO:

Que la presente investigación titulada: **“PREDICCIÓN DE ISLAS DE CALOR URBANO SUPERFICIAL EN EL ÁREA METROPOLITANA DE TRUJILLO (2017-2025) – PERÚ”** constituye la memoria que presenta el (la) / los Bachiller(es) Aaron Jhonatan Huaman Santa Cruz para obtener el título de Profesional de Ingeniero Ambiental, cuya tesis ha sido realizada en la Universidad Peruana Unión bajo mi dirección.

Las opiniones y declaraciones en este informe son de entera responsabilidad del autor, sin comprometer a la institución.

Y estando de acuerdo, firmo la presente declaración en la ciudad de Lima, a los 25 días del mes de abril del año 2022.

Nombres y apellidos del asesor

078

ACTA DE SUSTENTACIÓN DE TESIS

En Lima, Ñaña, Villa Unión, a los **25 días** día(s) del mes de **abril** del año 2022 siendo **las 08:30 horas**, se reunieron en modalidad virtual u online sincrónica, bajo la dirección del Señor Presidente del jurado: **Mg. Milda Amparo Cruz Huaranga**, el secretario: **Ing. Orlando Alan Poma Porras**, y los demás miembros: **Mg. Jackson Edgardo Perez Carpio y la Mg. Iliana Del Carmen Gutierrez Rodriguez**, y el asesor **Dr. Alex Ruben Huaman de la Cruz**, con el propósito de administrar el acto académico de sustentación de la tesis titulada: "Predicción de islas de calor urbano superficial en el Área Metropolitana de Trujillo (2017 – 2025) - Perú"

de el(los)/la(las) bachiller/es: a) **AARON JHONATAN HUAMAN SANTA CRUZ**

....b)

conducente a la obtención del título profesional de **INGENIERO AMBIENTAL**
(Nombre del Título profesional)
con mención en..

El Presidente inició el acto académico de sustentación invitando al (los)/a(la)(las) candidato(a)/s hacer uso del tiempo determinado para su exposición. Concluida la exposición, el Presidente invitó a los demás miembros del jurado a efectuar las preguntas, y aclaraciones pertinentes, las cuales fueron absueltas por el(los)/la(las) candidato(a)/s. Luego, se produjo un receso para las deliberaciones y la emisión del dictamen del jurado.

Posteriormente, el jurado procedió a dejar constancia escrita sobre la evaluación en la presente acta, con el dictamen siguiente:

Candidato (a): .... **AARON JHONATAN HUAMAN SANTA CRUZ** ....

CALIFICACIÓN	ESCALAS			Mérito
	Vigesimal	Literal	Cualitativa	
APPROBADO	17	B+	MUY BUENO	SOBRESALIENTE

Candidato (b): ....

CALIFICACIÓN	ESCALAS			Mérito
	Vigesimal	Literal	Cualitativa	

(*) Ver parte posterior

Finalmente, el Presidente del jurado invitó al(los)/a(la)(las) candidato(a)/s a ponerse de pie, para recibir la evaluación final y concluir el acto académico de sustentación procediéndose a registrar las firmas respectivas.

Presidente
Mg. Milda Amparo
Cruz Huaranga

Secretario
Ing. Orlando Alan
Poma Porras

Asesor
Dr. Alex Ruben
Huaman De la Cruz

Miembro
Mg. Jackson Edgardo
Pérez Carpio

Miembro
Mg. Iliana Del Carmen
Gutierrez Rodriguez

Candidato/a (a)
Aaron Jhonatan
Huaman Santa cruz

Candidato/a (b)

Estimation of the urban heat islands (UHI) in the Metropolitan area of Trujillo (2017-2025) – Peru

Predicción de islas de calor urbano superficial en el Área Metropolitana de Trujillo (2017-2025) – Perú.

Aaron Jhonatan Huaman Santa Cruz[1], Alex Huaman De La Cruz[2], Julio Angeles Suazo[3,4], Roberto Angeles Vasquez[5].

[1]Escuela Profesional de Ingeniería Ambiental, Universidad Peruana Unión, Lima, Perú

[2]Vicepresidencia de Investigación, Universidad Nacional Intercultural de la Selva Central Juan Santos Atahualpa, La Merced, Perú

[3]Escuela Profesional de Ingeniería Forestal y Ambiental, Universidad Nacional Autónoma de Tayacaja Daniel Hernández Morillo, Pampas, Perú.

[4]Facultad de Ingenieria industrial, Universidad Tecnológica del Perú, Lima, Perú

[5]Facultad de Ingeniería Civil, Universidad Nacional del Centro del Perú. Huancayo Perú

Corresponding author: Alex Huamán De La Cruz

Email addresses: alebut2@hotmail.com

Abstract

In this work, land surface temperature (LST) from moderate resolution Imaging Spectroradiometer (MODIS) sensor was used for the estimation data for 2001 to 2016 period. Forecasting of LST and identification of surface urban heat island (SUHI) on the Metropolitan Area of Trujillo (MAT), Peru for 2017-2025 period, it was carried out using the Quantile method and autoregressive integrated moving average (ARIMA). Monthly data between the period 2001and 2016 was used in the model study, which were separated for daytime and nighttime.The SUHI showed and increasing of 0.12^{o}C and 1.65^{o}C for daytime and nighttime, respectively. Results indicate that LST have increasing about 4.1^{o}C for daytime, and 6.08^{o}C for nighttime.

Keywords: Urban heat island, Trujillo, quantile method, ARIMA, Forecasting.

Introduction

The urban heat island (UHI) is a phenomenon observed worldwide that describes temperatures, which usually are warmer than its surroundings (Miles & Esau, 2020). The UHI shows higher temperatures due to change in land cover (soil surfaces replaced by pavement and building constructions), urban growth, cloudiness, wind direction and speed, humidity, population density, urban geometry (shape of buildings, natures of surfaces, size), and thermal and radiation properties (emissivity, heat capacity, and albedo (Bonan, 2015; Brandsma & Wolters, 2012; De Lucena et al., 2015; Kesavan et al., 2021).

The UHI formation or expansion is a global issue due to that contributes with the climate change or warming, water and air quality, and limit growth of vegetation (Ulpiani, 2021). These environmental factors have negative effect on the human health and environment which may potentially lead to exacerbate respiratory and cardiovascular illness, cause heat stroke, and even the death (Macintyre et al., 2021; Tong et al., 2021). Besides, more persistent and frequent heat waves were reported in the last decades, probably as consequence of urban heat island formation (Founda & Santamouris, 2017; The Guardian, 2021).

The Metropolitan Area of Trujillo (MAT) is a favorable place for occurring UHI, as already reported by Palme et al., (2016). It’s a region located in coastal northwestern Peru, bathed by the Pacific Ocean, with a humid of 80%, desertic landscapes, scarce or absent rains, and subtropical desert climate (warm season between january - march), which is affected by the Niño phenomenon. The MAT has a high urban population density (third region most populated from Peru) which has expanded for the four cardinal points. The MAT always had influence on nearby cities, causing their urban integration of these forming thus the current metropolis, which difficult distinguish its boundaries and conurbation metropolitan districts. These elements contribute to arise several conflict and environmental problems (thermal stress) that cause UHI.

The UHI phenomenon may be evaluated though air temperature from weather stations networks (automatic and conventional), land surface temperature (LST) data obtained from remote sensing instruments onboard airborne or satellite (Azevedo et al., 2016; De Almeida et al., 2021), or comparing air temperatures in urban and rural environments (Flores et al., 2016). It’s known that data *in situ* offers better resolution temporal, while remotely sensed data provided better spatial resolution.

The UHI effects reported on several metropolitan cities worldwide demand data-driven predicting models that can forecast UHI for the future. Among statistical methods used to UHI forecasting models are included regression analysis, principal component analysis, cluster analysis, factor analysis, weighted regression analysis, and spectral analysis (Kalyani et al., 2020). However, most regression analysis do not capture efficiently non-linear relationships, and their accuracy is insufficient (Wang et al., 2019). Nonetheless, Autoregressive Integrated Moving Average (ARIMA) model, reported provides accurate LST data through time series analysis in various studies (Lai & Dzombak, 2020; Mukadi & González-García, 2021).

Understanding the UHI is of great relevance inside current discussion in sustainable urban design. As heat is related strongly to health risks, particularly in urban cities and its surroundings, it is important to assess the surface (UHI) in different areas (urban and rural), and to have a better response to this phenomenon in the future. Thus, this works aims calculate the Surface (SUHI) using monthly data (2001 to 2016) using the Quantile method inside urban and rural areas from the metropolitan area of Trujillo. In addition, the ARIMA method was used to estimate the SUHI for period of 2017 to 2025 in the same areas.

Materials y Methods

Study area

Metropolitan area of Trujillo (MAT) is a core of the Trujillo city (8°6′43.2″S 79°1′43.68″W), Region Libertad, Peru (Figure 1). It has a total area of 1084 km^2 and comprises nine (e.g., Trujillo, Salaverry, Moche, La Esperanza) of eleven districts. Around the metropolitan area of Trujillo, high density residential are typical.

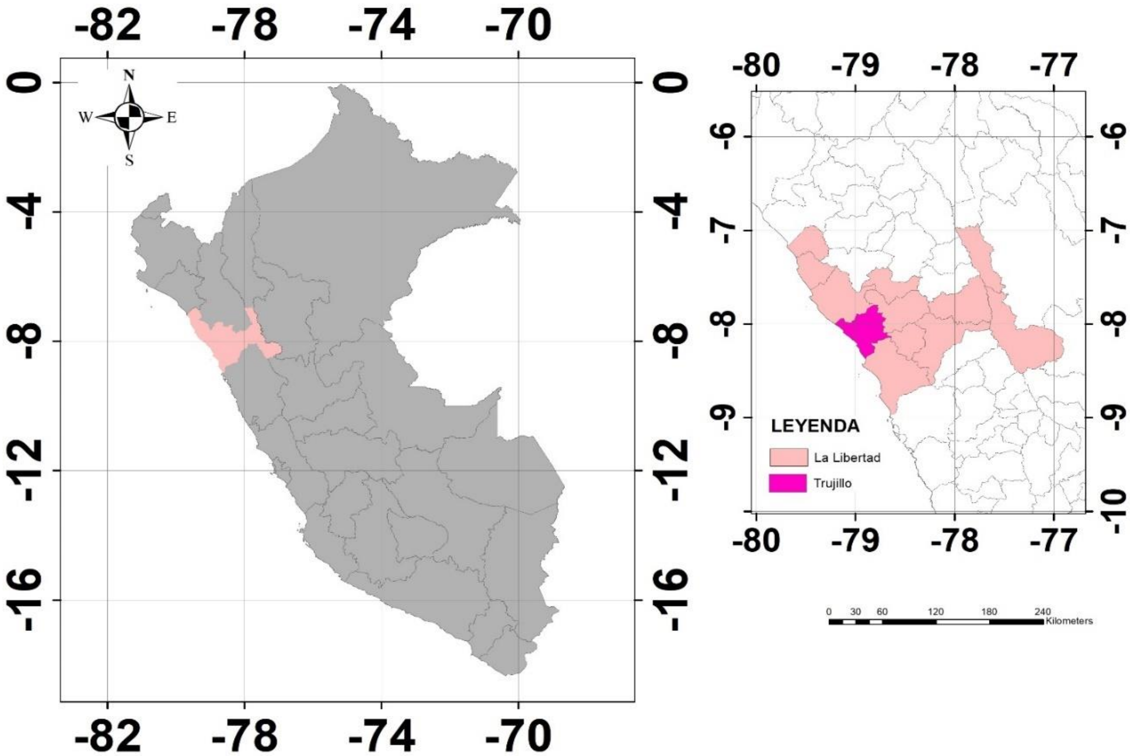

Figure 1. Location of the metropolitan area of Trujillo (MAT).

The climate is temperate, desert, and oceanic with daily average temperatures higher than 26ºC, and annual average precipitation of 275 mm. For instance, Figures 2A and 2B are shown the daytime (42°C and 44°C) and nighttime (21°C and 22.5°C) temperatures from the MAT in the 2001 and 2016 period, respectively. As is was noted between 2001 to 2016 periods is found an increase of temperature of 2°C for daytime and 1.5°C in nighttime.

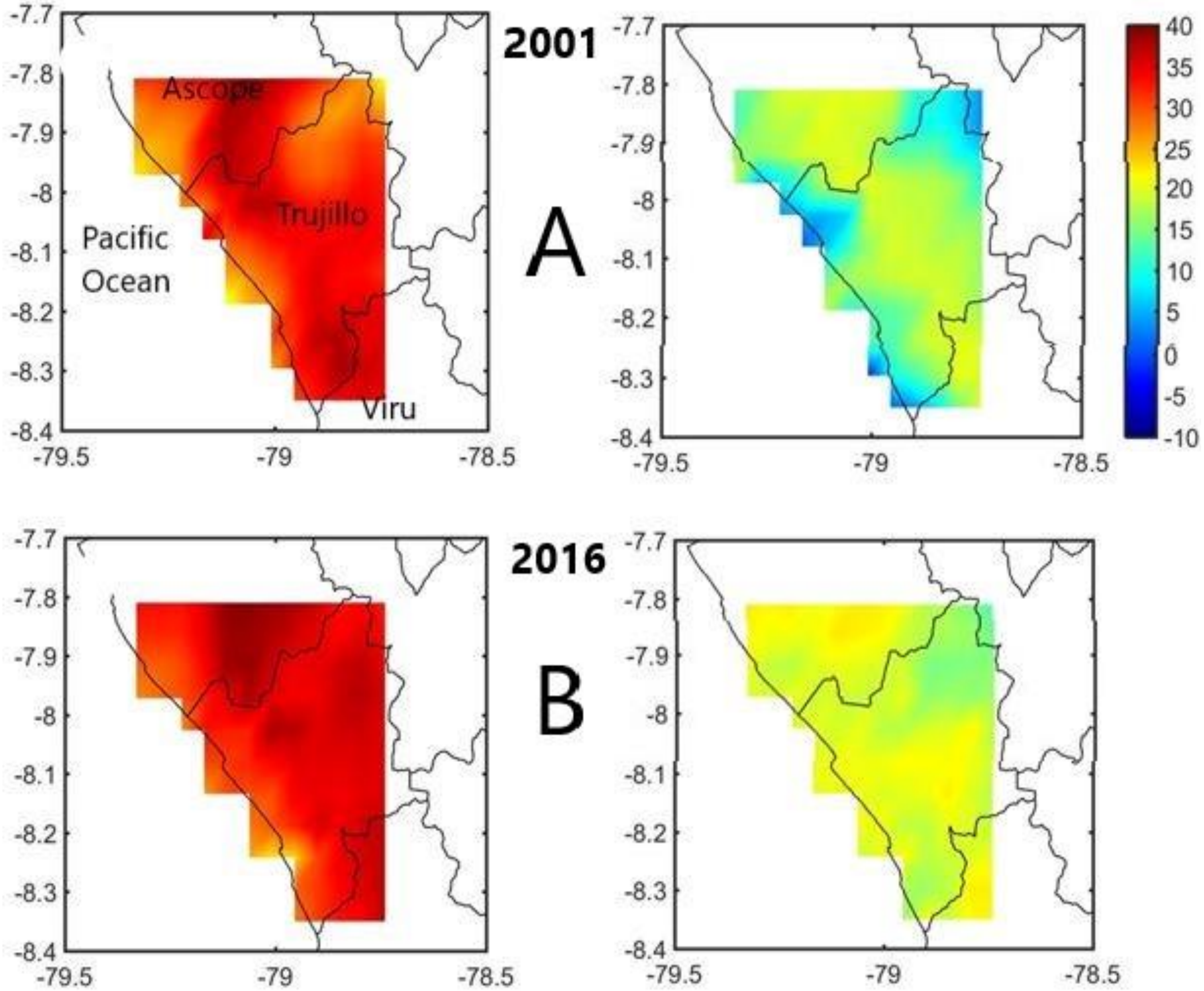

Figure 2. Average temperature from the metropolitan Area of Trujillo (MAT) at daytime (right) and nighttime (left) for 2001 (A) period; and Average temperature from MAT at daytime (right) and nighttime (left) for 2016 (B) period.

2.2 Land surface temperature (LST) data

The LST data was obtained using MODIS (Moderate resolution imaging spectroradiometer) sensor from Aqua and Terra (Dousset & Gourmelon, 2003). A monthly average of LST was performed at a spatial resolution of 5 km (0.05) which was enough to estimate the land surface temperature (LST). Urban and rural areas were separated using the MODIS Land Cover Type Climate Modelling Grid (CMG) product MCD12C1 with 0.05° resolution, whose categorization of LST was performed according to the International Geosphere-Biosphere Project (IGBP type 1) global vegetation classification scheme, who contain 17 land cover index (Table 1)(Schneider et al., 2003). For this, MOD11C3 Global CMG using monthly data composed of average LST at 0.05°

resolution was applied. Likewise, ‘urban and rural pixels from LST were separated using the MODIS Land Cover Type product (MCD12C1) at the same resolution (0.05°).

Table 1. Land cover Type 1: International Geosphere Biosphere Project (IGBP) global vegetation classification scheme.

Class	IGBP (Type 1) land cover index
0	Water
1	Evergreen needleleaf forest
2	Evergreen broadleaf forest
3	Deciduous needleleaf forest
4	Deciduous broadleaf forest
5	Mixed forest
6	Closed shrublands
7	Open shrublands
8	Woody savannas
9	Savannas
10	Grassland
11	Permanent wetlands
12	Croplands
13	Urban and built-up
14	Cropland/natural vegetation mosaic
15	Snow and ice
16	Barren or sparsely vegetated

Quantile method

Method proposed by Flores et al., (2016), where are estimated surface (UHI) intensities by the difference between quantile 0.95 of LST for urban area and the median of LST for rural area, data separated through Land Cover Type MODIS (MCD12C1) product with 0.050 resolution, and with the equation proposed by the same author.

$$SUHI\ intensity = Q_5^{urbano} - Q_3^{rural} \quad (2)$$

where Q_5^{urban} is the 0.95 quantile of LST distribution over urban area, and Q_3^{rural} is the median of LST distribution over rural area.

This quantile method was applied successfully when was estimated the SUHI for Iquitos city (Julio M Angeles Suazo et al., 2019), and three megacities from Africa (Julio Miguel Angeles Suazo et al., 2020).

Land surface temperature prediction

The Auto Regressive Integrated Moving Average (ARIMA) model was used to predict the SUHI value of the Metropolitan area of Trujillo for 2017-2025. This model predicts a value in a response time series through a linear combination of its own past values, and is used to identify dependent relationships between the observations (Silva et al., 2021). The approach provided by Box-Jenkins to building time series models is an iterative process, which can be summarized through the following equation:

$$X_t = \emptyset_0 a_t + \emptyset_1 a_{t-1} + \emptyset_2 a_{t-2} + \cdots + \emptyset_q a_{t-q} + c + \alpha_0 X_t + \alpha_1 X_{t-1} + \alpha_2 X_{t-2} + \cdots + \alpha_p X_{t-p} + a_t$$

Where Xt = time series data, ∅ = autoregression coefficient of the moving average part of ARIMA model, a_t= observed variable: SUHI 2001-2016), t= time to estimate: 2017-2025.

Results

Vegetation cover classification

Figure 3 shows the different types of vegetation cover classification (through IGBP methodology) inside the Metropolitan Area de Trujillo (MAT) for the period 2000 (A) and 2016 (B). As it is observed in Figure 3, the different colors represent different form of areas. For instance, the yellow color represents the urban area and built up from the MAT, grey color is represented by the barren and natural vegetation (cropland), and purple color shown the open and close shrublands. In the period 2000 the land cover from MAT consisted of 42% of open and close shrublands, 36% of barren and natural vegetation, and 22% of urban area and built-up. In 2016 period, urban area and built-up was represented by 25%, while open and close shrublands showed the 45%, and barren and natural vegetation it was represented by 30%. Between periods (A and B) it is noted an increasing of 3% for the urban area and built-up, and open and close shrublands. In contrast, a decreasing of 30% is observed for barren and natural vegetation.

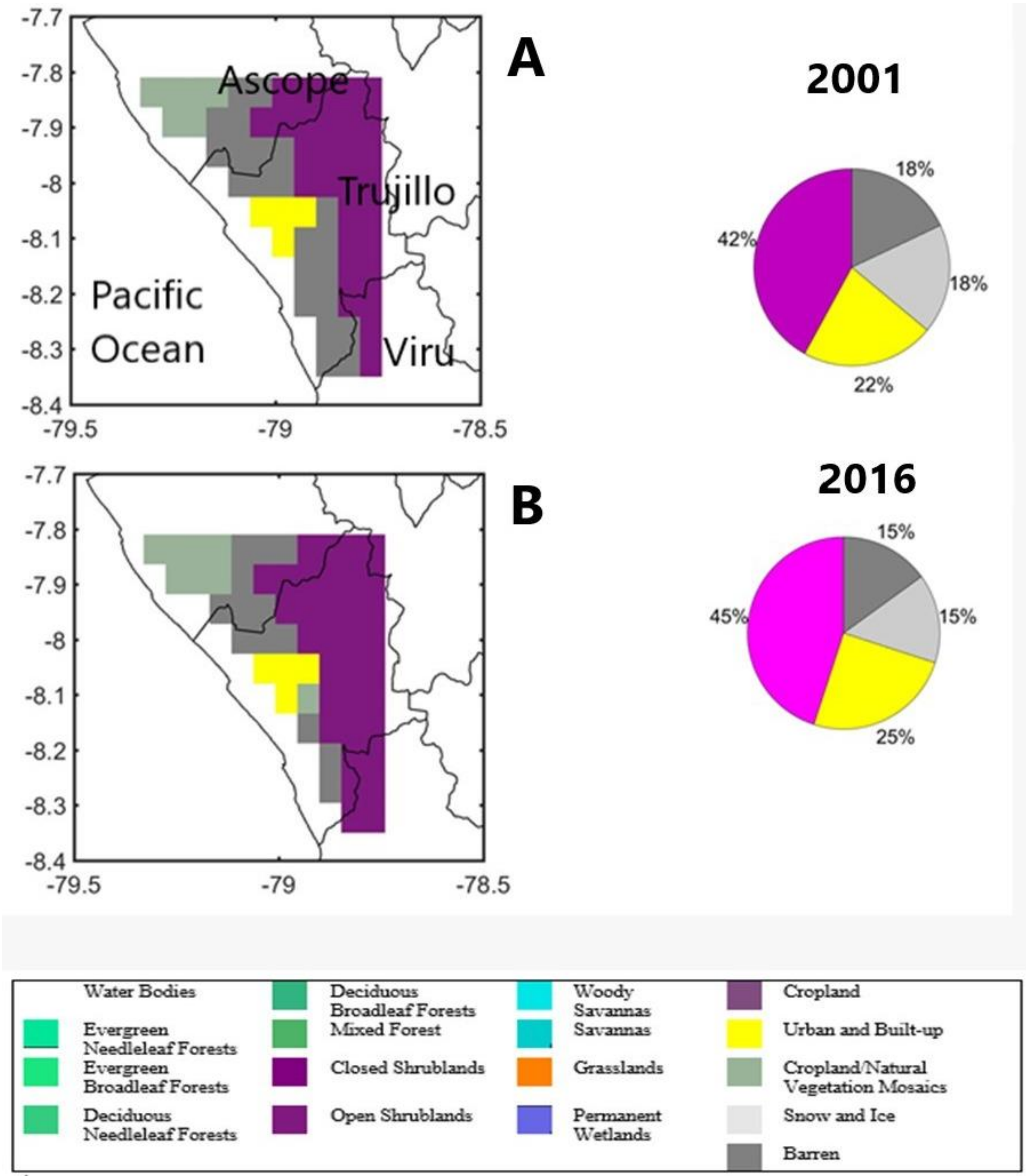

Figure 3. Type of land cover for the MAT using the IGBP methodology for the 2001 (A) and 2016 (B) period.

Land surface temperature average monthly

Figure 4 shows the monthly average LST between 2001 - 2016 for both daytime (fig. 4a) and nighttime (fig 4B) conditions at three different locations: urban center, frontier, and rural area from the Metropolitan Area of Trujillo (MAT). This presents the time evolution of LST (daytime and nighttime) for three different locations: central urban, boundary and rural. These graphics show long term (2001–2016) mean values and standard deviations of LST for the three locations. The time evolution of LST for day-time period (Fig. 4A) shows a well-marked seasonal variation for all locations, with higher amplitudes in central urban location and lower in rural location. The maximum mean LST for this period is observed in february for central urban (31 °C) and rural (34 °C) locations. Minimum mean values are observed in august for all locations, central urban (25 °C), boundary (25 °C) and rural (26 °C). At night-time period, time evolution of LST (Fig. 4B) shows a seasonal variation with similar amplitudes for all locations, with maximum values in february for central urban (19 °C) and for rural (15 °C) locations. Minimum mean values are observed in october for central urban (15 °C), boundary (11 °C) and rural (9 °C) locations. These results show an important thermal amplitude over the MAT for points inside urban area. This is observed from the differences of LST for the central urban and boundary locations. The thermal amplitude over urban area for day-time periods is approximately equal to 2 °C in summer months and close to 1 °C for winter months. For night-time periods, the thermal amplitude of urban area is reduced, with values close to 2 °C in winter months and close to 0.5 °C in summer months.

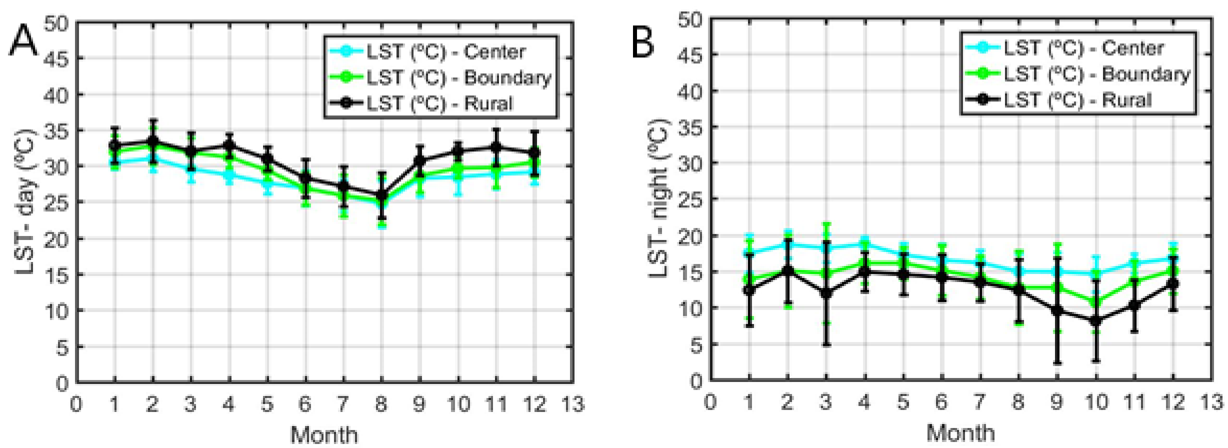

Figure 4. Time evolution of the LST for (a) daytime and (b) nighttime over the MAT at central urban (light blue line), boundary (green line) and rural (black line).

Surface urban heat island

The results for the long-term diurnal SUHI magnitudes (2001-2016) and the spatial extents for all months on the AMT using the quantile method are presented in Table 2. The diurnal IICUS obtained shows the maximum values in february (2.79°C) and lows in december (0.01°C). Likewise, the results using the statistical method of quantiles in the night periods obtained, show maximum values in february (2.88°C) and minimum values in may (0.01°C). Likewise, in Figure

5A, B shows the day and night ICUS is higher for the AMT in the summer months (december-february) and slightly lower in the months of may-august.

Table 2. Daytime and nighttime average of the SUHI and spatial extent with standard deviation for the MAT using the method developed by Flores (2016) for the period 2001-2016.

Month	Daytime quantile method	Nighttime quantile method'
January	2.15±2.07	2.05±2.62
February	2.79±2.21	2.88±1.57
March	2.61±2.05	1.84±1.11
April	0.30±1.19	0.57±0.86
May	0.69±1.37	-0.01±1.05
June	1.46±2.48	0.12±1.45
July	1.61±1.57	0.26±1.03
August	0.78±2.05	-0.40±2.30
September	-0.51±1.74	-1.15±1.74
October	-0.88±1.37	-1.06±1.48
November	-0.46±1.09	0.45±0.80
December	0.01±1.04	0.97±0.91

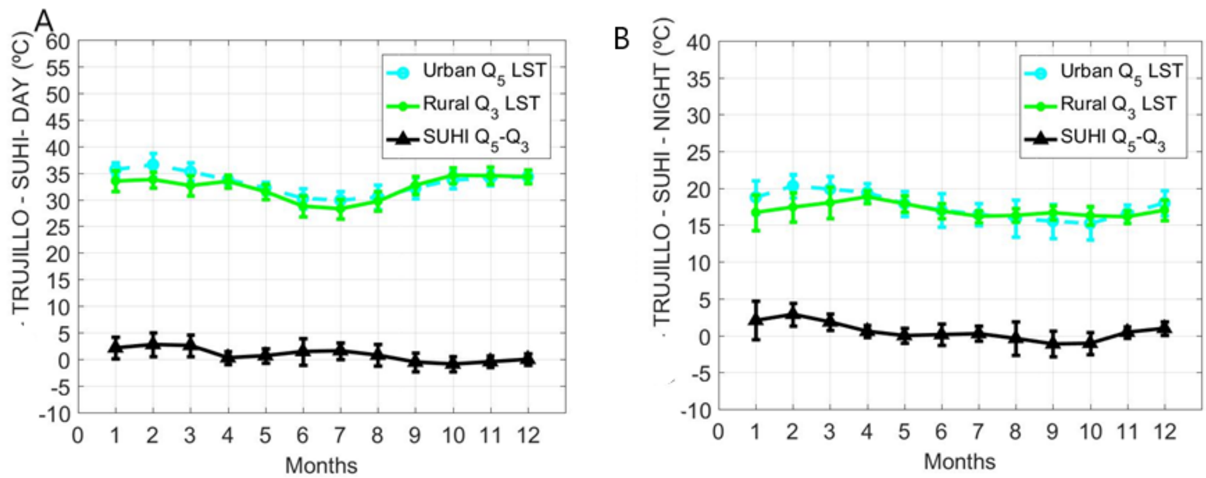

Figure 5. Time evolution of the SUHI for (a) daytime and (b) nighttime over the MAT at central urban (black line), boundary (light blue line) and rural (green line).

SUHI Prediction to 2025

The predictions with the ARIMA model for which the instruction in the R software was used: >forecast(model,h=50) where the ARIMA model and the number of points to be predicted on a monthly basis correspond to 6 years. The model behaves quite well within the time interval studied, and for this the ARIMA model has been built with the data from 2001-2016, to simulate until the year 2025. And in this way Figure N 6 is built, where the the blue curve represents the model predictions and the black curve represents the observations calculated with the quantile method (Flores et al., 2016).

The confidence intervals of the predictions are also shown with 80% in dark blue, and 95% in light blue. Figure 6 shows that the predictions with the model enclose the observed data within the confidence intervals and that the observed data at 95% can reach values close to 6 C.

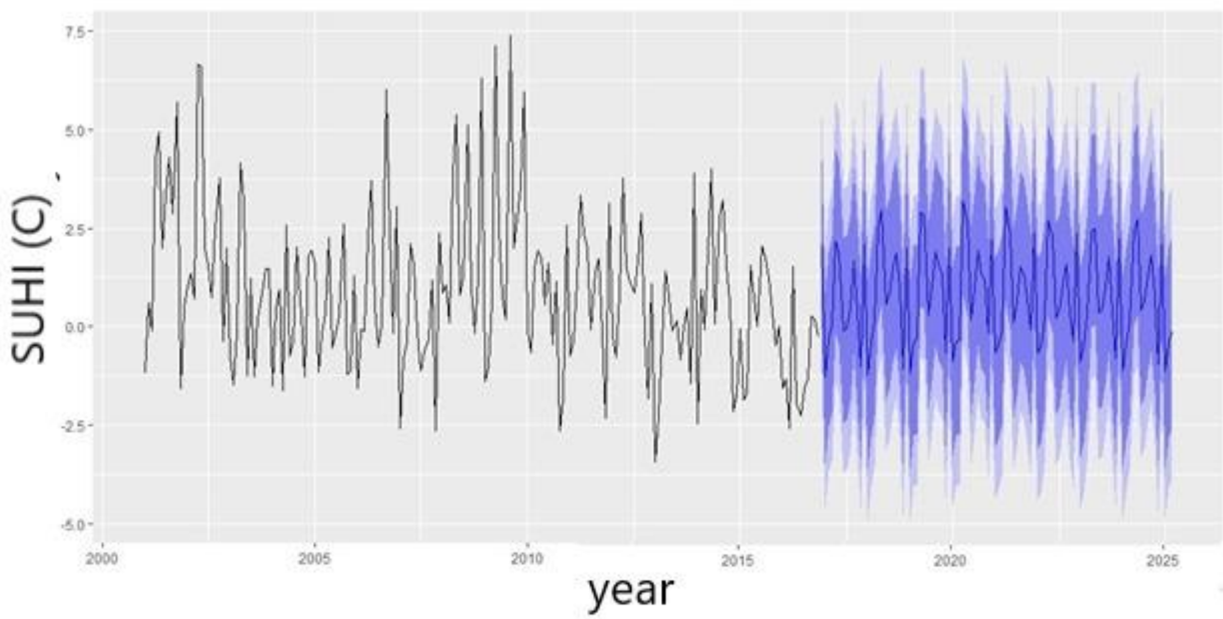

Figure 6. SUHI prediction for 2025

Discussion

According to SUAZO, it estimates the Surface Urban Heat Island Intensity (SUHI) during the period 2001-2016 for the Metropolitan Area of Iquitos (AMI), Arequipa (AMA), Huancayo (AMH), located in Peru. Where he used 2 methods: the first is the Stretcher method, the second method proposed by Flores, obtained from the Moderate Resolution Imaging Spectroradiometer (MODIS) sensor on board the TERRA and AQUA satellite. The AMI daily maximum SUHI shows the values in September (1.51°C) and minimum values in May (0.91°C). The night SUHI of the AMI presents maximum values in March (0.80°C) and minimum in November (-0.51°C).

On the other hand, the diurnal surface urban heat island intensity, obtained with the quantile method in the AMH, shows maximum values in March (6.94°C) and minimum in August (2.79°C), and the night SUHI obtained shows values maximum in August (6.06°C) and minimum in March (3.76°C). However, the daytime SUHI in the AMA shows maximum values in february (5.54°C) and minimum values in august (2.14°C), and the nocturnal SUHI presents maximum values in february (6.38°C) and minimum values in june (4.62°C).

Also using the same methodology during the period from 2001 to 2016, for the Metropolitan Areas of Cairo (AMC), Johannesburg (AMJ) and Lagos (AML), located in Africa. In the results obtained for the Gaussian method, in the IICUS daytime period, the monthly maximum occurred in the AML of 4.82 °C and the monthly minimum also in the AML of 0.01 °C. In the nighttime period, the monthly maximum was 4.64°C in the AMC and the monthly minimum in the AMJ was 1.30°C. For the quantile method, the daily maximum monthly IICUS was found in the AML of 5.78°C and the monthly minimum in the AMC of -1.56 °C. At night, the monthly maximum IICUS in the AMC was 4.88°C and the monthly minimum in the AML was 2.05°C.

Finally, FLORES estimates the long-term (2001-2014) surface urban heat island intensities (SUHI) for two urban areas: the São Paulo Metropolitan Area (MASP) and the Rio de Janeiro Metropolitan Area (MARJ) located in the southeastern region of Brazil. The methods use remote sensing data obtained from the MODIS sensor on the TERRA and AQUA satellites. Where he proposes that an advantage of the quantile method is that it can be used as an alternative procedure when the city shape is not ellipsoidal or when the spatial resolution is so high that it does not allow a Gaussian surface adjustment. One drawback is that it will not be possible to calculate a SUHI footprint area because the method does not fit the LST data to any surface. In general, the quantile method can be useful as a complementary analysis of the Streutker method.

T**able 3.** LST mean and standard deviation values for urban and rural classes in the 2001, 2016, and 2025 for daytime.

			2001s		
	urban	**Standard deviation**	**rural**	**Standard deviation**	**Amplitude**
LST (ºC)	28.30	3.6	29.64	3.62	-1.34
			2016s		
	urban	**Standard deviation**	**rural**	**Standard deviation**	**amplitude**
LST (ºC)	30.34	1.5	31.63	2.79	-1.29
			2025s		
	urban	**Standard deviation**	**rural**	**Standard deviation**	**amplitude**
LST (ºC)	32.4	1.2	33.6	1.1	-1.2

Table 4. LST mean and standard deviation values for urban and rural classes in the 2001, 2016, and 2025 for nighttime.

	2001s				
	Urban	**Standard deviation**	**rural**	**Standard deviation**	**amplitude**
LST (°C)	16.22	2.53	11.87	4.49	4.35
	2016s				
	Urban	**Standard deviation**	**rural**	**Standard deviation**	**amplitude**
LST (°C)	19.17	0.75	16.65	3.09	2.52
	2025s				
	Urban	**Standard deviation**	**rural**	**Standard deviation**	**amplitude**
LST (°C)	22.3	1.02	19.6	1.1-	2.7

4 Conclusion

Daytime SIHU shows maximum values in february (2.79°C) and minimum values in december (0.01°C). Likewise, the results in the night periods show maximum values in february (2.88°C) and minimum values in may (0.01°C), producing an increase in the surface temperature of the urban area with respect to the rural area of almost 3°C; this is due to urban expansion in the 16 years of study (2001-2016) and the decrease in vegetation cover in the AMT. An advantage of the quantile method is that it can be used as an alternative method when the shape of the city is not ellipsoidal, or the spatial resolution is so high that it does not allow an adjustment of the Gaussian surface. One drawback is that it would not be possible to calculate an SUHI area footprint because it does not fit any surface.

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