MODELING SPATIAL-TEMPORAL SURFACE HEAT ISLANDS AT FORMOSA-GO CITY: CHALLENGES AND OPPORTUNITIES USING ORBITAL REMOTE SENSING DATA

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Abstract

This study was intended to evaluate the space-time dynamics of surface heat islands at Formosa-GO city. The methodology consisted of a bibliographical review and Digital Processing of Satellite Images of medium and high spatial resolution. The results show the neighborhoods that are most impacted by the action of surface heat islands at Formosa-GO city, considering observations of one of the hottest months of the year, in the last seven years. Densely built neighborhoods do not show a strong positive correlation with surface heat islands.

Key words: Earth Observation, Climate Adaptation, Smart and Sustainable Cities.

1. Introduction

The techniques associated with the treatment of data from Orbital Remote Sensing have evolved significantly since the beginning of the 1970s (NOVO, 1989). In this perspective, it has enabled the modeling, analysis and monitoring of various phenomena that occur on the Earth's surface, contributing directly to decision-making within the scope of sustainable economic development (NOVO et al, 1994). In the range of possibilities, data from Orbital Remote Sensing represent one of the potentialities for studies on the urban environment and the acting phenomena (spatial and temporally), highlighting the current context of global climate change, where these centers become , increasingly, directly impacted (IPCC, 2007).

Considering the vertiginous process of urbanization in developing countries, among which Brazil stands out (YUNES, 1971; HOGAN, 1993); it is observed that the emergence and growth of a significant part of the cities occurs, mainly, without proper planning, with rapid transformations in the landscape, occupation of risk areas, areas of restricted use, among others; corroborating the triggering of several socio-environmental problems. In this sense, it is observed that, historically, the disorderly growth of cities is strongly related to a significant increase in extreme events of different natures, with emphasis on heat wave events, due to the fact that, for the most part, they affect, with risks to life, the most different agents and segments of society around the world (IPCC, 2007, 2021; ISDR, 2009).

The urban environment itself is very complex and has its own dynamics, and as cities expand, for example, there is the creation of artificial spaces, especially with the suppression of the natural vegetation cover and the soil sealing, and the impacts of expansion are not reduced

to morphological aspects, but mainly to climate aspects (DANNI-OLIVEIRA, 1987), where sources of heat and energy consumption are increased, with the consequent increase in sources emission of polluting gases, thus aggravating the constraints on quality of life, with the gradual increase in the vulnerability of these environments, which already add to other aspects, for example, socioeconomic inequalities. According to Saccaro Júnior e Coelho (2016), in this century, the search for resilience measures and the premise of building sustainable cities is one of the greatest challenges facing global climate change and paradigm of sustainable development.

In this context, the present study aimed to give answer to the following questions:

1 – Considering the recent space-time dynamics, which neighborhoods at Formosa-GO city have been most affected by the action of surface heat islands?

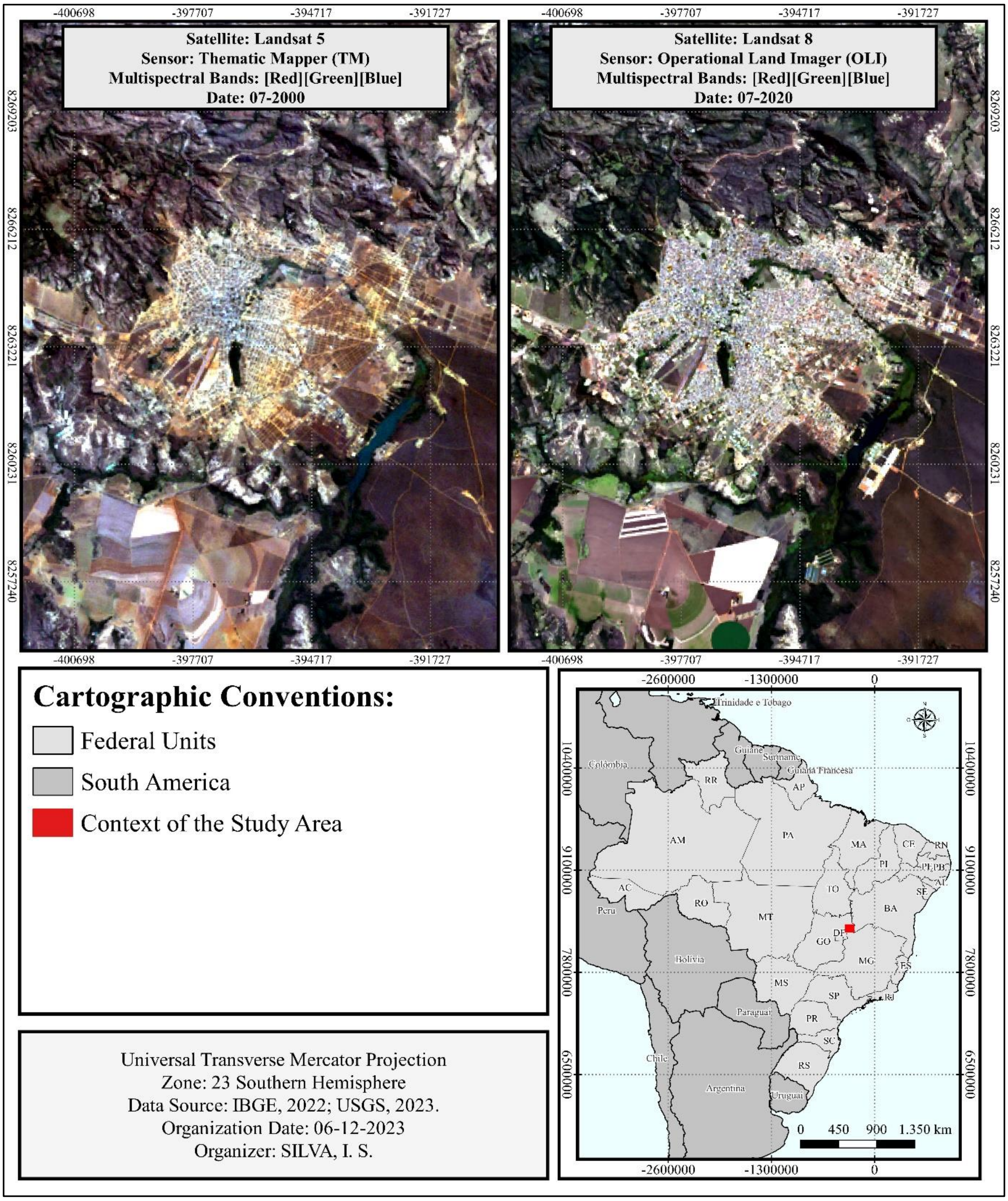
2 – Nowadays, is there a relationship between densely built neighborhoods and higher surface temperatures?

For that, optical PDI techniques were used, specifically, under images from the Operational Terra Imager – OLI and Thermal Infrared Sensor – TIRS sensor system, aboard the Landsat 8 satellite, taking into account one of the hottest months, namely, the month of September (09). Finally, through data analysis, the average values of Land Surface Temperature observed over time (September of the year 2014, 2015, 2016, 2017, 2018, 2019, 2020 and 2021) and space (neighborhoods of the city of Formosa-GO) to the amount of built-up area in each neighborhood, identified and mapped from the high spatial resolution PDI, specifically Planet&NICFI data (Planet&NICFI, 2023).

The study is justified by the fact that tropical cities are naturally hot and the generation and action of heat islands are one of the main factors responsible for thermal discomfort and the restriction of environmental quality and quality of life and well-being of human beings. In this way, the space-time modeling of surface heat islands and their behavior in relation to different conditions of land cover and use can corroborate directly in urban territorial and environmental planning, opportunely subsidizing the formulation and implementation of public policies with emphasis on the expanding neighborhoods, the new neighborhoods, aiming climate adaptation, sustainable development and quality of life in these multiple-use spaces.

3. Methodology

The Formosa-GO city (Figure 1) is located in the Northeast portion of the Goiás state, approximately 80 km from the central localization of the Federal District (Brasília), and about 280 km from the state capital, Goiânia. According to data from the last Demographic Census carried out by the Instituto Brasileiro de Geografia e Estatística (IBGE, 2010), in 2010 the urban population of the municipality of Formosa-GO was 92,023, which means an increase of 45% in relation to the total urban population existing in the year 2000, showing a pattern of markedly accelerated urbanization.



Organization: The author.

The study methodology consisted in bibliographic review and a high and medium spatial resolution satellite PDI. In this sense, Planet&NICFI images were used for semi-detail mapping (1:25.000) of the built-up areas of the entire urban area of the city of Formosa-GO; and Landsat 8 images (Operational Terra Imager – OLI and Thermal Infrared Sensor – TIRS) in the modeling of surface heat islands. The methodological procedures implemented ranged from the delimitation of the study area, acquisition, pre-processing, processing and post-processing of data from orbital remote sensing, with their respective analysis and understanding. Specifically, the analysis and subsequent graphical representation of the data was performed using R language.

The data processing routines were carried out on the Google Earth Engine platform, through access to the Planet&NICFI and Landsat 8 (OLI) image collections, taking into account images whose cloud cover percentage is less than 10% in the respective orbit-point, adopting the month of September (09) as a time window, as this is also the month with the lowest cloud cover in the context of the study area. About the digital classification of the Planet&NICFI images, a Kappa coefficient of 0.93 was obtained, demonstrating that the classification algorithm (Random Forest) obtained a good learning performance, considering the training data. On the Landsat 8 (OLI) data processing, sequences, with the objective of modeling the Land-Surface Temperature, were executed considering the applications of the following equations:

Equation 1):

$$\boldsymbol{L\lambda = MLQcal + AL}$$

Where:

Lλ = Radiance of the top of the atmosphere (Watts/(m2 * srad * µm));

ML = Rescaling multiplicative factor of each spectral band;

(Radiance_Mult_Band_x, where x is the band number);

AL = Additive scaling factor of each spectral band;

(Radiance_Add_Band_x, where x is the band number);

Qcal = Standard product (DN) quantified and calibrated pixel values.

After applying the first equation, the atmospheric correction of the images was carried out according to the principles provided by the Atmospheric Correction Parameter Calculator, considering the local values of Transmittance, Upwelling Radiance and Downwelling Radiance, considering Equation 2.

Equation 2):

$$CV_{R2} = \frac{CV_{R1} - L\uparrow}{\varepsilon\tau} - \frac{1-\varepsilon}{\varepsilon} L\downarrow$$

Where:

CVR2 = cell value of atmospheric correction as radiance;

CVR1 = cell value as radiance from Equation 1

L↑ = upwelling radiance;

L↓ = downwelling radiance;

τ = transmittance;

ε = emissivity (value 0.95).

After atmospheric correction, equation 3 was applied to convert the values into temperature expressed in Kelvin (K), subsequently subtracting 273.15 in order to convert the temperature into Celsius (ºC), as specified in Equation 3.

Equation 3):

$$T = \frac{K2}{In\left(\frac{K1}{L\lambda} + 1\right)}$$

Where:

T = Effective temperature on the satellite in Kelvin;

K2 = Calibration constant 2 – value – 1 321.08;

K1 = Calibration constant of 1 – value – 774.89;

L = Radiance,(Watts / (square meter ster ** mm)).

4. Results

From the modeling and mapping of the Land Surface Temperature in the context of the city of Formosa-GO, referring to the month of September (09) of the year 2014, 2015, 2016, 2017, 2018, 2019, 2020 and 2021, it is presented in Figure 1 the change observed in the Land Surface Temperature between 2014 and 2021, considering the respective neighborhoods. It can be seen that, comparatively (2014 and 2021), all neighborhoods recorded an increase in Land Surface Temperature values (September month), and the neighborhoods that recorded the highest rates of increase in Land Surface Temperature were Jardim das Américas, Vila Pantanal, Conjunto Netinho, Vila Aurora and Vila Santos. In these neighborhoods, it was observed that, specifically, the Land Surface Temperature values in the year 2021 were at least 9 ° C higher compared to that observed in the same month of the year 2014.

Spatially, it was observed that in the month of September, historically, one of the hottest months of the year, the highest temperatures occur mainly in its Northeast, Northwest and Center-South portions of the city, where one can also observe the predominance of occupied spaces by different types and patterns of buildings, in addition to many areas of bare soil. It should be noted that the areas of bare soil occur mainly in newer neighborhoods, where land use is not yet consolidated, with a notable occurrence of subdivisions. It is emphasized that, in these neighborhoods, there is practically no presence of green spaces, that is, the presence of ecological parks and/or public green spaces for recreation, citing the example of the Parque Ecológico Municipal Mata da Bica, located in the Formosinha neighborhood, central portion from the city; in addition, the presence of trees spatially distributed along the street beds is slightly rarefied.

When studying the impacts of the implementation of green areas and reforestation in relation to the surface heat islands in the Formosinha neighborhood, Silva (2023) observed that areas of bare soil contributed directly to the occurrence of higher temperatures, while the presence of public green spaces for recreation, such as the aforementioned Parque Ecológico Municipal Mata da Bica, act in the opposite direction, that is, it exerts a strong influence in relation to the occurrence of lower surface temperatures, consequently, providing a greater thermal comfort. Among the numerous ecosystem services and benefits that the population can enjoy from public green spaces for recreation in their neighborhoods, the following can be highlighted: reduction of the effects of air pollution, conservation of water resources, better soil permeability conditions in cases of floods, landscape enhancement, conservation of fauna and flora, reduction of temperatures and wind speed, better conditions for leisure activities, among others (IPCC, 2021).

In the context of global climate change, public policies with emphasis on reforestation and creation of green spaces, especially ecological parks, have a positive impact on climate adaptation in cities. Figure 1 shows the observed changes in Land Surface Temperature between 2014 and 2021, in the neighborhoods of the city of Formosa-GO.

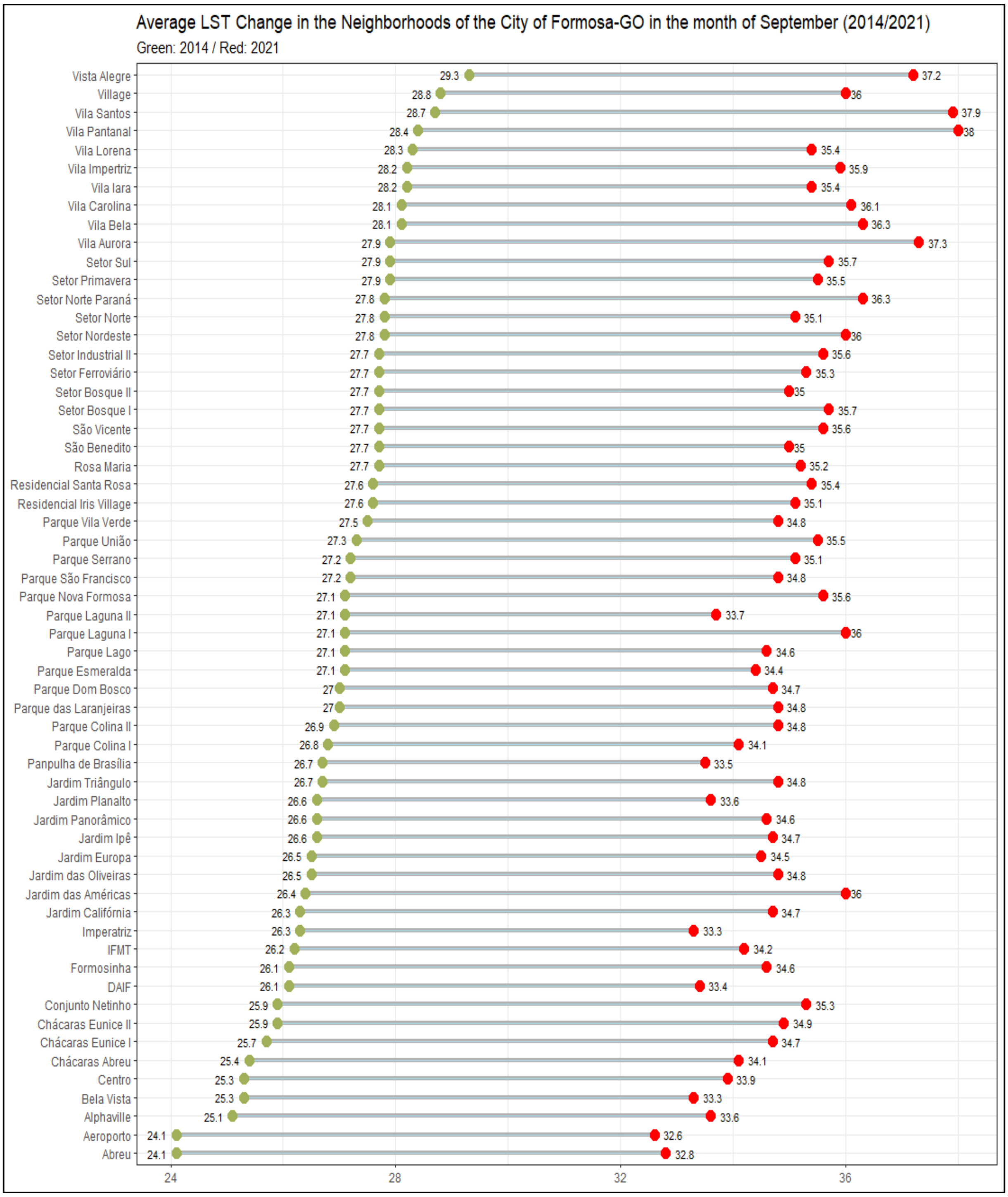


Figure 1 – Change in Land Surface Temperature (2014/2021). Organization: The author.

With the objective of understanding if more recently, there is a relationship between densely built neighborhoods and higher Land Surface Temperature, Graph 1 presents the relationship between the percentage of build area and the Land Surface Temperature in the neighborhoods at Formosa-GO city, year 2021. It is possible to observe that there is a weak correlation between the variables. In this way, it is understood that the influence of the presence of vegetation on temperatures should be considered, as well as the relevance of analyzing not only a specific date, but also the dynamics of a time series. This demonstrates the importance of analyzing earth observation data cubes (FERREIRA et al., 2020). Despite this, it is noted that about 54% of the neighborhoods have more than 50% of their area constructed, waterproofed.

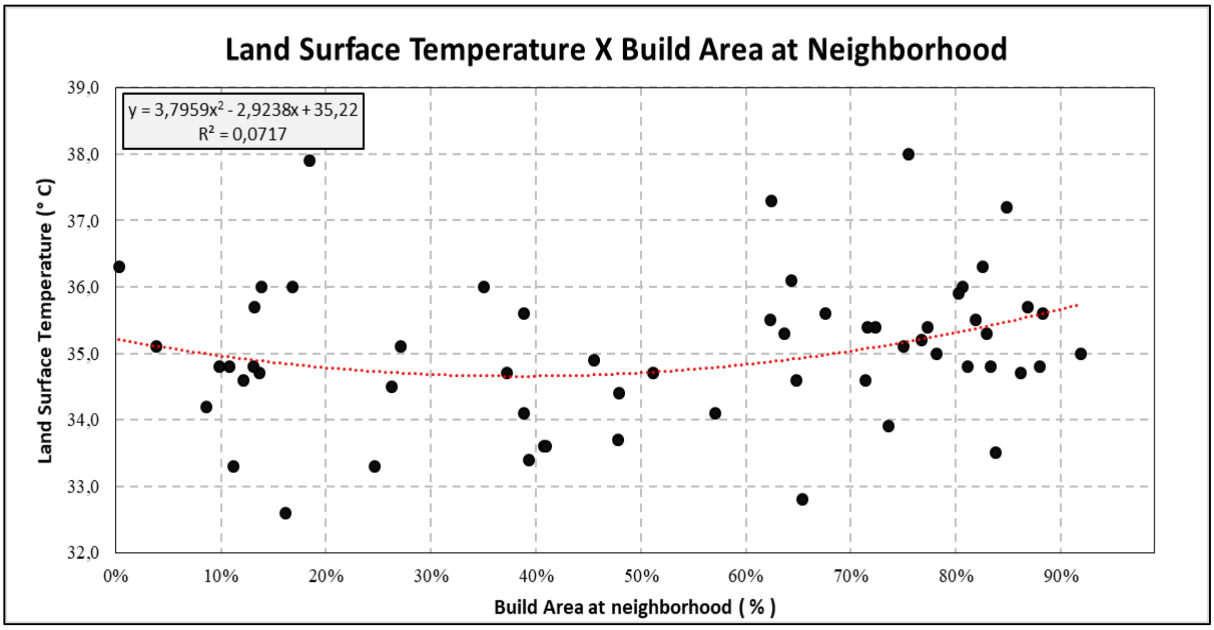


Figure 2 – Correlation between Land Surface Temperature and Build Area at neighborhood. Organization: The author.

Still regarding the relationship between Soil Surface Temperature and land cover and use (WENG et al, 2004; JENSEN, 2009), considering the spatial layout of the neighborhoods in the city of Formosa-GO, the importance of the detailed mapping of green areas, as well as the analysis of their influence on the landscape scale, on the effect of atmospheric warming in the respective neighborhoods. It is suggested that these efforts prioritize, in addition to satellite data with adequate resolution for the scale, successive fieldworks and data collected in situ. In this way, it is so important do not disregard the relevant analysis of meteorological data.

5. Conclusions

From this exploratory and descriptive study, it was demonstrated how the population of Formosense, together with formulators and implementers of public policies within the city of Formosa-GO, can take initiatives that will benefit the neighborhoods that have been most impacted with the action of surface heat islands. For example, planning and creating green spaces for recreation in neighborhoods, providing better conditions for adaptation and resilience to climate change and, consequently, well-being and quality of life for the population. As previously presented and discussed, all neighborhoods have been affected by the action of surface heat islands, with the most intensely affected being: Jardim das Américas, Vila Pantanal, Conjunto Netinho, Vila Aurora and Vila Santos.

Considering the action of surface heat islands and densely built neighborhoods, no correlation was observed between the variables. In this sense, in the case of initiatives that make use of Orbital Remote Sensing data, it is suggested that future studies work with the modeling and space-time analysis of the dynamics of surface heat islands using data cubes. In agreement with Silva (2023), it is also suggested that a detailed mapping of green spaces be considered, in order to better understand patterns in relation to land cover classes and land use, bearing in mind that the targets have intensities of emittance proportional to its surface temperature (BAPTISTA, 2012). It is noteworthy that there are few published scientific studies on quality of life indicators ate Formosa-GO city, and this study is a small contribution. It is hoped that these results may motivate other future studies, with greater complexity and depth of analysis, by demonstrating the importance and contributions that the use of data from Orbital Remote Sensing provides to urban climate studies.

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