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Análise da correlação entre cobertura vegetal e temperatura de superfície na área urbana do município de Ji-Paraná, RO, Amazônia Ocidental entre 1990 e 2020

Analysis of the correlation between vegetation cover and surface temperature in the municipality of Ji-Paraná, RO, Western Amazon

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Resumo: Esta pesquisa teve como objetivo evidenciar as consequências que a ocupação desordenada causou sobre a temperatura de superfície no município de Ji-Paraná/RO no período entre 1990 e 2020. Teve como instrumento de trabalho a plataforma de sistemas de informações geográficas QGis v3.10, usando imagens dos satélites Landsat 5 Thematic Mapper (TM), Landsat 7 Enhanced Thematic Mapper Plus (ETM+) e Landsat 8 Orbital Land Imager (OLI) e Thermal InfraRed Sensor (TIRS), obtidas pelo Serviço Geológico dos Estados Unidos (USGS – U.S. Geological Survey). Essas imagens foram utilizadas para obter dados de Índice de Vegetação por Diferença Normalizada (NDVI), estimativa da Temperatura de Superfície e classificação do uso do solo pelo método Random Forest. De acordo com os resultados, a área urbana do município perdeu 11,77% de vegetação nativa em comparação ao que havia em 1990 e a área antropizada cresceu 58,53%. Com isso, a temperatura média subiu de 35,03 °C [34,85 °C; 35,22 °C] em 1990 para 47,04 °C [46,82 °C; 47,26 °C] em 2020. Com esses dados fica evidente que a supressão da vegetação nativa pode influenciar diretamente a temperatura de superfície e o conforto térmico da população residente no município de Ji-Paraná. Logo, faz-se necessária a execução adequada do Plano Diretor vigente.

Palavras-chave: Ilhas de calor; Geoprocessamento; Supressão Vegetal.

Abstract: This paper aims to highlight the consequences the disorderly occupation caused on the surface temperature in Ji-Paraná/RO between 1990 and 2020. The research is based on geoprocessing tools, such as QGis v 3.10, Landsat 5 Thematic Mapper (TM), Landsat 7 Enhanced Thematic Mapper Plus (ETM +), Landsat 8 Orbital Land Imager (OLI) and Thermal InfraRed Sensor (TIRS) satellites, obtained by the United States Geological Survey (USGS). Images were used in order to analyze the Vegetation Index by Normalized Difference (NDVI), estimation of Surface Temperature and Land Use Occupation using the Random Forest method. According to the results, Ji-Paraná's urban area lost 11,77% of native vegetation in comparison to 1990 figures. Moreover, the entropized area grew 58,53%. As a result, the average temperature has rose from 35,03 °C [34,85 °C; 35,22 °C] in 1990 to 47,04 °C [46,82 °C; 47,26 °C] in 2020. It is evident that native vegetation suppression can directly influence the Surface Temperature and population thermal comfort. Therefore, it is necessary to properly implement the current Master Plan..

Keywords: : Heat islands; Geoprocessing; Vegetal supression.

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1. Introduction

In the early 1970s, the Brazilian government started a movement to promote the opening of the borders of the Amazon (TURCHI, 1981). Since then, the States corresponding to the biome began to receive immigrants from all parts of the country. However, Rondônia was the main target. Fearnside (1984) explains that Rondônia works as a "gate" to the Amazon, through which a growing flow of migrants enters the region from the Center-South region, where the mechanization of agriculture and the concentration of land tenure are forcing the rural *exodus* of small farmers to urban areas.

Carbone (2014) highlights that unplanned human occupation leverages the problem of urban infrastructure, concentrates housing and reduces green areas, providing the occurrence of heat islands with direct implications for climate comfort. This growing disorderly occupation influences the quality of life of those who live in these heat islands, which Giguère (2009) defines as regions with a high rate of civil construction, characterized by a large capacity for thermal energy storage. In his study, Pereira (2019) found that areas sealed with buildings and smaller amounts of green areas result in the formation of heat islands. De Sousa Leite et al. (2020) found a high correlation between anthropized built-up area and the increase in temperature in the urban area of Teresina/PI.

Regarding urban planning, the lack of zoning in the city of Ji-Paraná resulted in the occupation of environmentally vulnerable areas, such as Permanent Preservation Areas (APP, Área de Proteção Permanente in Portuguese), which in urban areas play a role in climate regulation (RODRIGUES 2019). Studies show the necessity to preserve these APPs, as Amaral (2017) highlights the importance of preserving urban forests to provide ecosystem services related to carbon sequestration. Pinheiro et al. (2018) emphasize that the increase in afforestation in urban areas brings numerous social, economic and environmental benefits to the city, as it maintains urban biodiversity. In addition, they work as a great environmental filter, reducing atmospheric and noise pollution, influencing thermal comfort and attenuating heat islands. In order to develop mitigating measures for environmental issues, in 1992 the Eco-92 Global Conference took place - a meeting where several countries came together to set goals for the benefit of the environment.

At the Eco-92, it was established that each country would build its own Agenda 21. According to Cordani (1997), the Agenda emphasizes great challenges for humanity such as development and its economic and social dimensions, as well as environmental challenges that deal with conservation and management. of natural resources. The United Nations (UN), in 2015, created the 2030 Agenda. Goal 11 presents goals to be met by that year, aiming at a world with sustainable cities, where there is access to safe housing and guaranteed by urbanization methods sustainable. This would reduce the number of deaths from environmental catastrophes related to water, such as losses linked to housing on the slopes of streams. These policies directly contribute to surface temperature attenuation, as they aim to preserve APPs with riparian vegetation.

Orbital remote sensing products are essential for monitoring the relationship between vegetation loss and surface temperature increase on multitemporal and multispatial scales, making it possible to analyze the spatial organizations of various natural and anthropic phenomena and their interactions (TEIXEIRA, 2015). Thus, this work is guided by two main questions: “How does the surface temperature behave over the years and with the increase in anthropization in the urban area of Ji-Paraná?” and “Is there a relationship between vegetation and surface temperature in the urban area of Ji-Paraná?”

Given the facts, this research aims to analyze, through the use of orbital remote sensing products, the relationship between vegetation index and surface temperature in the municipality of Ji-Paraná/RO.

2. Methodology

Figure 1 presents a flowchart with the steps of the work, which are discussed below.

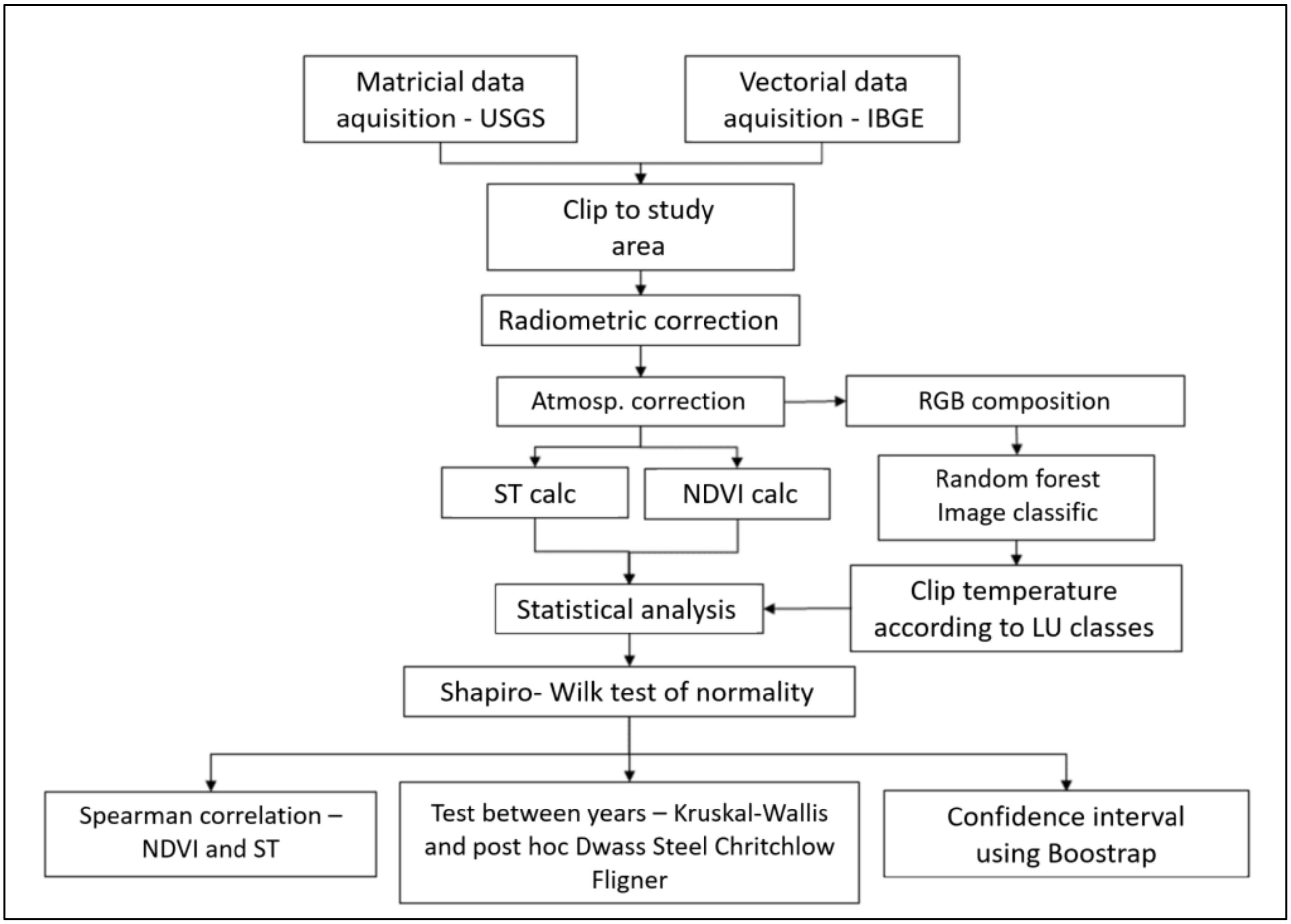


Figure 1 – Research workflow. Surface Temperature (ST) and NDVI.
Source: Authors (2021).

2.1 Study area

The studied area was the urban region of the municipality of Ji-Paraná, located at the geographic coordinates latitude 10°52'54.1" South and longitude 61°56'27.3" West. The city, which has an urban population of 130,009 inhabitants, was chosen because there is little information in this area for the region (IBGE, 2021). The vector data with the census sectors were obtained by the IBGE virtual platform (2021). The study area can be seen in Figure 2.

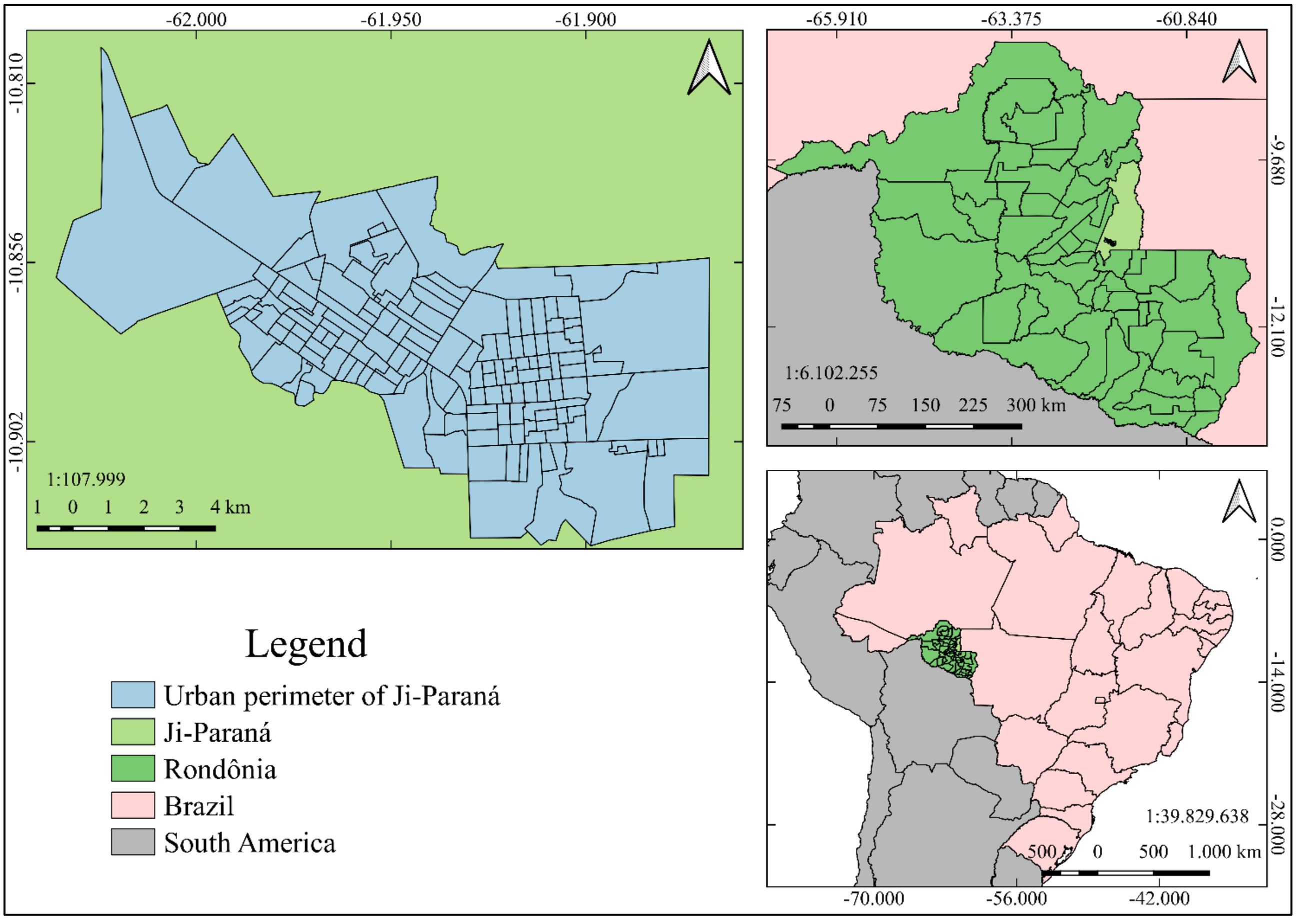


Figure 2 – Location of the study area.
Source: Authors (2021).

The research was carried out through the acquisition of orbital remote sensing images, between years: 1990, 2000, 2011 and 2020. The images were chosen between the months of July and September, always respecting the same season of the year, which, for the region, are the least rainy. Studies applying orbital remote sensing data in the Amazon face the challenge of the presence of clouds in the period from October to mid-March. Thus, there is a lower probability of finding clouds, which could make the analysis of the images unfeasible. However, the year 2010 was rejected, and the same season was chosen for the successor year. This choice is justified by the fact that all Landsat 5 images showed clouds and all Landsat 7 images were defective in the year 2010. The images were processed by QGis V 3.10.14 "A Coruña" (QGIS.org, 2021) for being a free program. All processing was performed using the SIRGAS 2000 Coordinate Reference System.

According to the Köppen classification, the climate of the region has Aw characteristics, which is characterized by a relatively high rainfall with a clear dry period (BASTOS, 1982).

2.2 Images acquisition

The images used were from the Landsat 5 Thematic Mapper (TM), Landsat 7 Enhanced Thematic Mapper Plus (ETM+), Landsat 8 Orbital Land Imager (OLI) and Thermal InfraRed Sensor (TIRS) satellites and obtained by the USGS (2021). The Landsat mission was selected because of over forty years of providing high quality orbital remote sensing products. The scenes and other information of the images used are described in Table 1.

Table 1 – Information on the images used.

Satellite	Spectral bands	Sensor	Spectral resolution (µm)	Path/row	Sensing date
Landsat 5	B1 - Blue	TM	0,45 - 0,52	231/068	20/07/1990
Landsat 5	B2 - Green	TM	0,52 - 0,60	231/068	20/07/1990
Landsat 5	B3 - Red	TM	0,63 - 0,69	231/068	20/07/1990
Landsat 5	B4 – Near Infrared	TM	0,76 - 0,90	231/068	20/07/1990
Landsat 5	B6 - Thermal	TM	10,4 - 12,5	231/068	20/07/1990
Landsat 7	B1 - Blue	ETM+	0,45 - 0,52	231/067	24/08/2000
Landsat 7	B2 - Green	ETM+	0,53 - 0,61	231/067	24/08/2000
Landsat 7	B3 - Red	ETM+	0,63 - 0,69	231/067	24/08/2000
Landsat 7	B4 – Near Infrared	ETM+	0,78 - 0,90	231/067	24/08/2000
Landsat 7	B6 - Thermal	ETM+	10,4 - 12,5	231/067	24/08/2000
Landsat 5	B1 - Blue	TM	0,45 - 0,52	231/067	30/07/2011
Landsat 5	B2 - Green	TM	0,52 - 0,60	231/067	30/07/2011
Landsat 5	B3 - Red	TM	0,63 - 0,69	231/067	30/07/2011
Landsat 5	B4 – Near Infrared	TM	0,76 - 0,90	231/067	30/07/2011
Landsat 5	B6 - Thermal	TM	10,4 - 12,5	231/067	30/07/2011
Landsat 8	B2 - Blue	OLI	0,45 - 0,51	231/067	24/09/2020
Landsat 8	B3 - Green	OLI	0,53 - 0,59	231/067	24/09/2020
Landsat 8	B4 - Red	OLI	0,64 - 0,67	231/067	24/09/2020
Landsat 8	B5 – Near Infrared	OLI	0,85 - 0,88	231/067	24/09/2020
Landsat 8	B8 – Panchromatic	OLI	0,5 - 0,68	231/067	24/09/2020
Landsat 8	B10 - Thermal	TIRS	10,6 - 11,19	231/067	24/09/2020

Source: Authors (2021).

2.3 Surface temperature

To determine the surface temperature (ST), the method described by Karen Zanter (2019) was used, which consists of transforming the referring band into the thermal infrared band, converting the gray levels to radiance, according to equation 1.

$$L'_\lambda = M_\rho * Q_{cal} + A_\rho \quad (1)$$

Where:

Lλ' = Spectral radiance ($\frac{W}{m^2 * sr * \mu m}$);

Mρ = Multiplication factor for band conversion;

Qcal = Calibrated pixel level value in DN = Thermal Band;

Aρ = Additive brightness scaling factor for the band.

However, L'λ is not true because it does not consider the solar elevation angle. For this, equation 2 is used, which considers the solar angle and must be chosen according to the region studied.

$$L_\lambda = \frac{L'_\lambda}{cos\,(\theta_{SZ})} = \frac{L'_\lambda}{cos\,(\theta_{SE})} \quad (2)$$

Where:
Lλ = Top of atmospheric planetary reflectance
θSE = Local sun elevation angle
θSZ = Local solar zenith angle
And, later using the value found (Lλ), convert a for temperature to degrees Kelvin (K) by equation 3.

$$TB = \frac{K_2}{lnln\,(\frac{K_1}{L_\lambda}+1)} \quad (3)$$

Where:
TB = Maximum brightness temperature of the atmosphere (K);
Lλ = Spectral Radiance ($\frac{W}{m^2 * sr * \mu m}$);
K1 = Band-specific thermal conversion constant from metadata;
K2 = Band-specific thermal conversion constant from metadata.
Then, the proportion of vegetation proposed by Carlson and Ripley (1997) is calculated, represented by equation 4.

$$PROPVEG = \left(\frac{NDVI - NDVI_{min}}{NDVI_{max} - NDVI_{min}}\right)^2 \quad (4)$$

Methods for calculating NDVI are provided in section 2.4.

Having done this, the next step is to calculate the emissivity, a method proposed by Artis and Carnahan (1982) and Weng et al. (2004). According to equation 5.

$$e = (0{,}004 \times PROPVEG) + 0{,}986 \quad (5)$$

Finally, the surface temperature is calculated (equation 6), still following the method of Artis and Carnahan (1982) and Weng et al. (2004):

$$T = \frac{TB}{1 + \left(\lambda \times \frac{TB}{c2}\right) \times ln\,(e)} \quad (6)$$

Where:
T = surface temperature (°C);
λ = wavelength of emitted radiance;
TB = brightness temperature;
c2 = h*c/s = 1,4388*10 – 2 m K = 14388 μm K;
e = emissivity.

2.4 NDVI

To differentiate vegetated from non-vegetated areas, the Normalized Difference Vegetation Index or Normalized Difference Vegetation Index (NDVI) was used, a method proposed by Rouse et al. (1974). According to Shimabukuro (1998), this index is related to biophysical parameters of the vegetation cover, such as biomass and leaf area index. In addition to minimizing the effects of scene lighting, surface slope and acquisition geometry, this index influences the spectral response of the remote sensor bands. For Melo (2011), the NDVI is an application of the enhancement processes by mathematical operations between bands of satellite sensors (equation 6).

$$NDVI = \frac{NIR-RED}{NIR+RED} \quad (6)$$

Where:
NIR = band corresponding to near infrared;
RED = band corresponding to red.

According to Assalve (2017), the result of this calculation is an image that varies from -1 to +1, corresponding to regions with no vegetation cover to those with large plant biomass. Values close to -1 indicate areas with little vegetation and values close to +1 indicate areas with greater plant biomass. Shimabukuro (1998) explains that for the generation of vegetation index images, it is important to transform the digital numbers into reflectance values, in order to obtain values comparable with those of other works available in the literature..

2.5 Image classification

For the classification of land use and occupation, the Random Forest (RF) algorithm was used, as it is a supervised, ensemble-type classifier with the capacity to process a high amount of data with high accuracy. The classifier consists of a collection of classifiers structured in trees {h (x, k), k = 1, n...} where k are identically distributed random vectors (BREIMAN, 2001). This is a supervised classification method that uses a machine learning algorithm. The method consists of a combination of classifiers, where each classifier contributes a single vote to assign the most frequent class to the input vector. (RODRIGUEZ GALIANO, 2012).

According to Pal (2005) the RF classifier uses the Gini Index as a selection measure, which measures the impurity of an attribute in relation to the classes. In training the pixel is randomly selected and assigned to some class Ci, the Gini index can be written as:

$$\sum\sum_{j\neq i}(f(C_i,T)/|T|)(f(C_j,T)/|T|) \quad (7)$$

Where f (Ci, T) /|T| is the probability that the selected pixel belongs to class C.

Then, the program will create a tree of classes, and in each class there must be several samples of pixels corresponding to it. In this way, it is necessary that in the training there is as much sample as possible for better results.

The accuracy of the images was evaluated using the Kappa Index, where the following values were obtained: 0.94; 0.96; 0.92; and 0.94 for the years 1990, 2000, 2011 and 2020, respectively. The classes were defined as native vegetation, pasture, water and anthropization, which consists of built-up areas. In the urban area of the municipality there is no presence of agriculture of perennial and non-perennial crops.

2.6 Statistical analysis

Descriptive statistical analyzes were performed, using bootstrap with 9,999 repetitions, and inferential analyzes with the help of the Jamovi program version 1.6 (2021) and the SPSS v26 program (IBM Corp., 2019). For all analyses, alpha equal to 0.05 was used.

The set of values for the years was tested for normality using the Shapiro-Wilk test, where:

$$\begin{cases} \text{H0: Data is parametric} \\ \text{H1: Data is not parametric} \end{cases}$$

To compare the existence of differences between TS and NDVI for the years studied, without distinction of classes, the Kruskal-Wallis test (1952) was used, rejecting H0, followed by the pairwise test of Dwass-Steel-Chritchlow- Fligner for interaction between years, described by Dwass (1960), Steel (1960;1961) and Douglas and Michael (1991), where:

$$\begin{cases} \text{H0: Data do not present significant difference} \\ \text{H1: Data present significant difference} \end{cases}$$

3. Results and discussion

3.1 Land use

With the results of the analyses, it is noted that the municipality of Ji-Paraná has undergone a strong process of urbanization. According to figure 3, in 1990, the anthropized area was 17.18% of the total area, and in 2020 it reached 27.03%. If we compare the extent of anthropization in 1990 with that of 2020, there is a growth of 58.53% in the area. On the other hand, 2020 showed a significant loss in native vegetation: in 1990, native vegetation amounted to 32.07% of the total area, rising to 20.30% in 2020. The pasture area went from 48.77% in 1990 to 50 .12% in 2020.

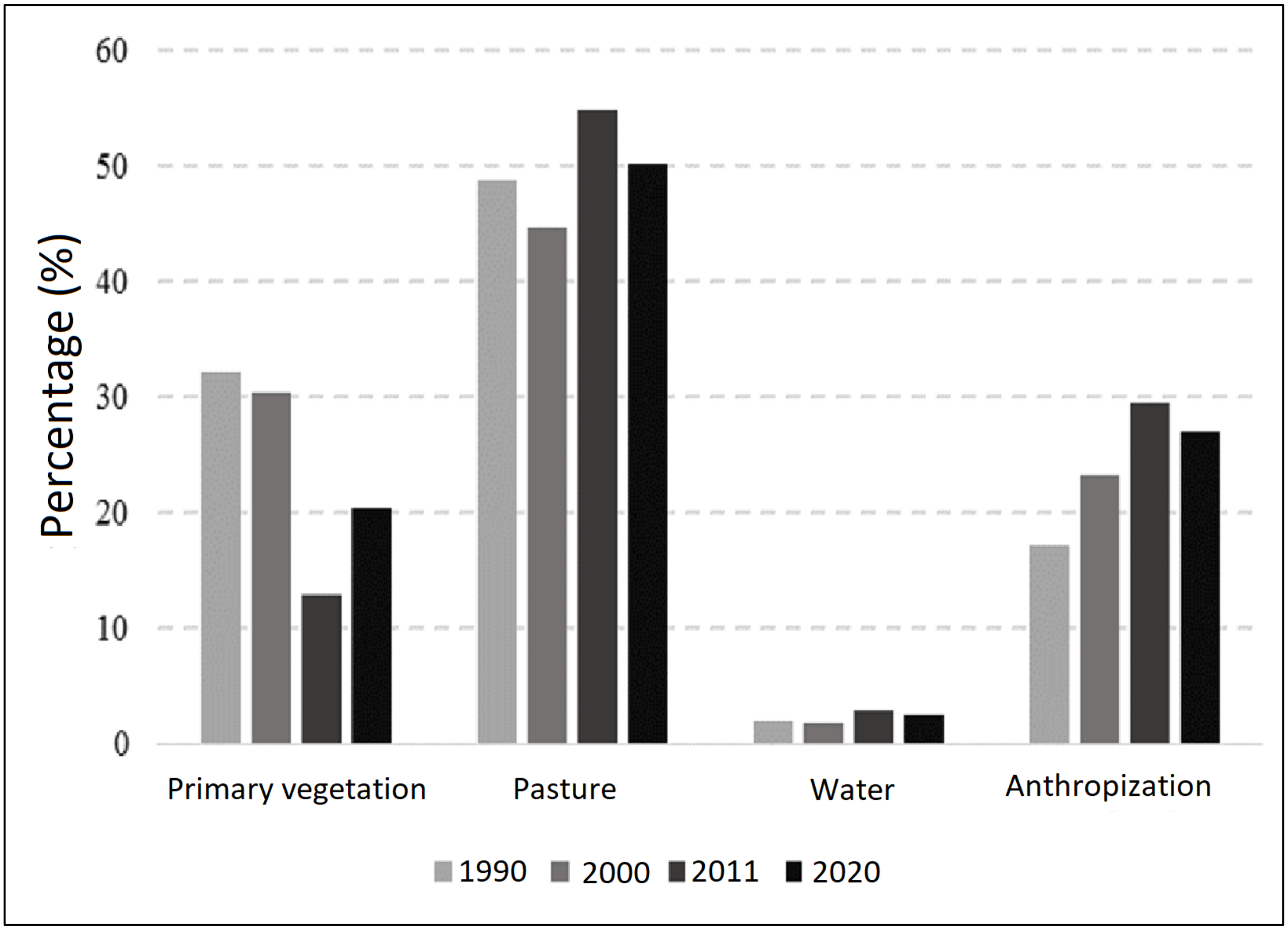


Figure 3 – Proportion of land use and alteration of classes between different years.
Source: Authors (2021).

It is possible to observe that the process of intense anthropization between 1990 and 2020, with great loss of native vegetation. However, from 2000 onwards, it is noted that anthropization increased in the same way that native vegetation decreased, while pasture increased. Despite the inversely proportional behavior, it does not mean that this vegetation was converted directly to an anthropized area, but that one area grew at the same rate as the other decreased.

Between 2000 and 2011, there was the greatest reduction in the area of native vegetation and an increase in the anthropized area. However, from 2011 to 2020, the areas did not vary as much as the previous interval, however, they showed growth. This may have been due to the influence of Amazon colonization policies initiated in 1970. In 2012, the government took measures to contain the advance of deforestation through the Forest Code, Law 12,651, of May 25, 2012

(BRASIL, 2012), which provides for the protection of native vegetation. Furthermore, this increase may be related to areas of planted teak forest.

The water had few variations in relation to the area. However, there was a peak in 2011. In the following year, the variation, however, decreased again. However, it is known that water is linked to precipitation, influencing the variation of the surface area according to the flow. Water was recorded, mainly in the Machado River, which runs through the city. Its flow may vary according to rainfall regimes.

The results seen in Figure 3 are easily seen in Figure 4: the loss and transformation of vegetation are evident. The riparian forests existing in 1990 were converted into pastures, leaving little vegetation around the Ji-Paraná River, which divides the municipality. For Ribeiro (2018), with the removal of vegetation, the river banks are unprotected causing soil erosion. As a consequence, the silting process of the river was intensified.

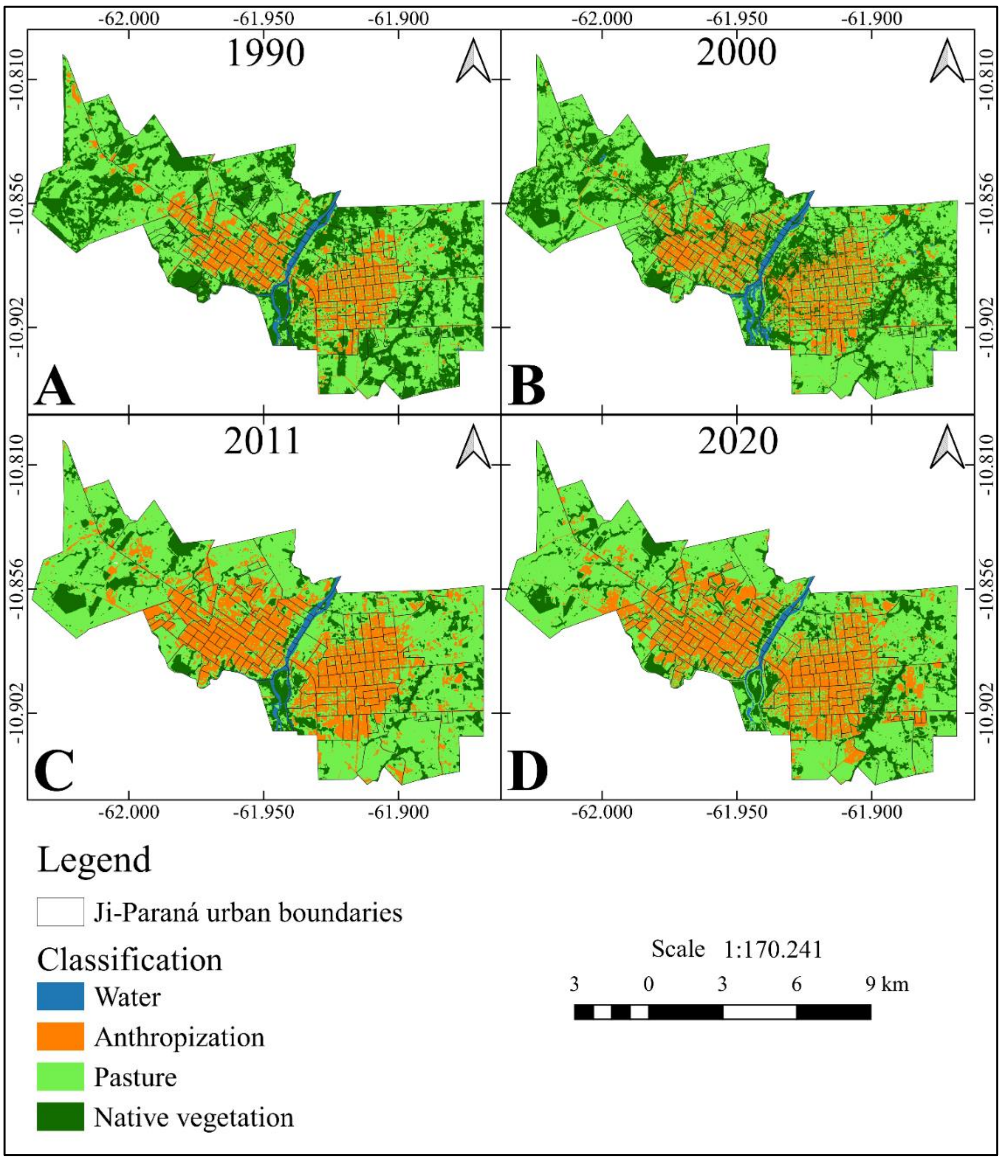


Figure 4 – Classification of land use for the different years studied. Being Panel A - 1990; Panel B - 2000; Panel C - 2011; and Panel D - 2020.
Source: Authors (2021).

3.2 Correlation between ST and NDVI

To check the normality of the data, the Shapiro-Wilk test was used. All years (treatments) analyzed presented p-value < 0.001. Thus, the null hypothesis is rejected and it is assumed that the data are not normal. Table 2 shows the values of the analyzes.

Table 2 – Descriptive statistics of the variables Normalized Difference Vegetation Index (NDVI) and Surface Temperature (ST), presenting the number of samples (n), the average, upper bootstrap and lower boostrstrap (α = 0.05), value Shapiro-Wilk W and Shapiro-Wilk p-value.

	NDVI 1990	ST 1990	NDVI 2000	ST 2000	NDVI 2011	ST 2011	NDVI 2020	ST 2020
n	1094	1094	1094	1094	1094	1094	1094	1094
Mean	0,22	35,03	0,19	38,27	0,17	40,84	0,21	47,04
Bootstrap - superior	0,229	35,22	0,2	38,45	0,17	41,05	0,21	47,25
Bootstrap - inferior	0,22	34,85	0,19	38,09	0,16	40,64	0,2	46,82
Bias	-1E-04	0,002	0	-0,003	0	-8E-04	0	-0,003
Shapiro-Wilk W	0,983	0,99	0,987	0,994	0,981	0,946	0,979	0,969
Shapiro-Wilk p	<0,001	< 0,001	< 0,001	< 0,001	< 0,001	< 0,001	< 0,001	< 0,001

Source: Authors (2021).

In Table 3, the NDVI and ST data for the different years were compared by hypothesis testing, seeking to understand whether the vegetation index and surface temperature varied significantly from one year to another. According to the p-value, the null hypothesis is rejected, assuming that there is a difference between the treatments, with the exception of the comparison between the year 2000 and 2020 for the NDVI variable.

Table 3 – Pairwise hypothesis test using the Dwass-Steel-Chritchlow-Fligner test for Normalized Difference Vegetation Index (NDVI) and Surface Temperature (ST) between different years (α = 0.05).

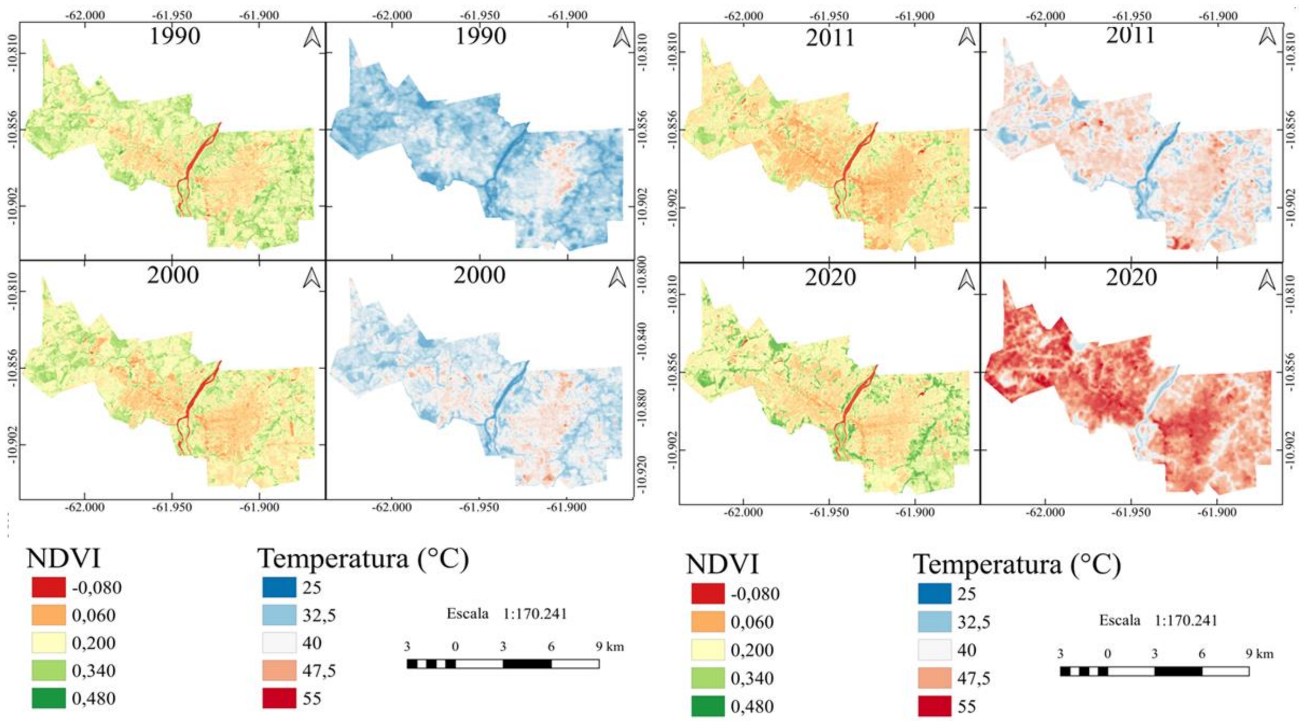
Pairwise comparisson - NDVI		W	p-value	Pairwise comparisson - TS		W	p-value
1990	2000	-13,04	< 0,001	1990	2000	31,8	< 0,001
1990	2011	-25,9	< 0,001	1990	2011	44,9	< 0,001
1990	2020	-9,07	< 0,001	1990	2020	55,9	< 0,001
2000	2011	-14,69	< 0,001	2000	2011	27,7	< 0,001
2000	2020	3,34	0,085	2000	2020	52,6	< 0,001
2011	2020	17,38	< 0,001	2011	2020	45,5	< 0,001

Source: Authors (2021).

Given the results, it is possible to observe that the vegetation index underwent significant changes over the years analyzed. Authors such as Schüle et al. (2018) and Gallo et al. (2019) found that the NDVI underwent changes when performing paired comparisons, as did the present study.

Tests for ST were significant in all cases (p-value < α). Thus, it is assumed that the difference in ST averages will vary significantly in the years analyzed. Alatorre et al. (2016) and Fathizad et al. (2017) recorded in their study that when comparing the surface temperature between different years, these showed significant changes in the studied areas. These results corroborate those found in this research.

Changes in land use and occupation directly contribute to the increase in surface temperature. Figures 5A e 5B illustrates these variations. Value ranges have been standardized for all years in order to faithfully present changes over time.



Figures 5A e 5B – Normalized Difference Vegetation Index (NDVI) and Surface Temperature (ST) in ºC for the different years. Panel – A: NDVI in 1990. Panel – B: TS in 1990. Panel – C: NDVI in 2000. Panel – D: TS in 2000. Panel – E: NDVI in 2011. Panel – F: TS in 2011. Panel – G: NDVI in 2020. Panel - H: TS in 2020.
Source: Authors (2021).

Looking at panel B, the surface temperature in 1990 varied by 17.20 °C, expressing the highest values in the area of dense urbanization. The maximum, 44.88 °C, is found precisely in places with lower vegetation, precisely where there is low photosynthetic activity. For Alves et al. (2017), with the decrease of the NDVI, the surface temperature tends to increase. The river channel and its surroundings have milder temperatures. The region on the right side of the river at the time comprised the main commercial hub of the municipality, which explains the largest area of ST.

Analyzing the year 2000, according to panel D, the temperature variation increased the amplitude to 20.6 °C. The areas with the highest temperatures began to expand along the entire length, and the region left to the river is still warmer, as it was in 1990. The loss of vegetation between 1990 and 2000 is not as expressive in relation to the 2000 interval. to 2011, as described in figure 3.

As a result, in 2000, the maximum surface temperature increased by 4.79 °C compared to the previous year. The increase in temperature has not only occurred in urbanized areas, but also in areas where native vegetation has been suppressed and converted to pastures. Santos (2018) found that when there is a decrease in the average NDVI values, an increase in the average surface temperature consequently occurs. And when the average NDVI value increases, consequently the average surface temperature decreases.

In 2011, panel F, the amplitude was 24.97 °C, indicating an increasing increase since 1990. In the interval between 2000 and 2011, the largest increase in reddish area, which represents surface temperature, occurred: the left and right sides of the urban center begin to equalize in temperature values, a consequence of the expansion of urbanization shown in Figure 3 - from 2000 to 2011, this is the highest growth rate in urban areas. The influence of vegetation loss on surface temperature is also noted. In some pasture sites, the values are similar to the anthropized sites. This can happen as a result of fires carried out to form pastures, leaving the soil exposed.

The year 2020, panel H, presented the highest values for surface temperature, reaching maximums of 55.53 °C - an amplitude of 21.59 °C and an average of 47.04 °C [46.82 °C ; 47.26 °C], the means will be presented followed by the confidence interval calculated by bootstrap. The year has its area almost entirely covered by reddish tones, indicators of high temperatures, except for areas where there is still native vegetation and around the Ji-Paraná River. For Souza et al. (2015), intense urban growth results in an urban microclimate and, consequently, in an increase in surface temperature.

Analyzing figure 6, which shows the evolution of the ST and NDVI for the different years in a boxplot format, one can see the increasing increase in surface temperature (panel A) and the decrease in the vegetation index (panel B). The year 1990 presented lower temperatures and amplitude. It is possible to observe that until 2011 the first quartile of the following year did not exceed the third quartile of the previous year. However, 2020 surpassed the third quartile and still kept more than 75% of the data above 40°C. Several authors such as Siddique and Ghaffar (2019), Solangi et al., (2019) and Rahmad et al., (2019) when studying the relationship between NDVI and ST, proved that these variables are inversely proportional: where there is low photosynthetic activity, surface temperature is lower. Thus, it is corroborated with the results of the present research. Analyzing the NDVI, it is noted that it kept a growing drop until 2011.

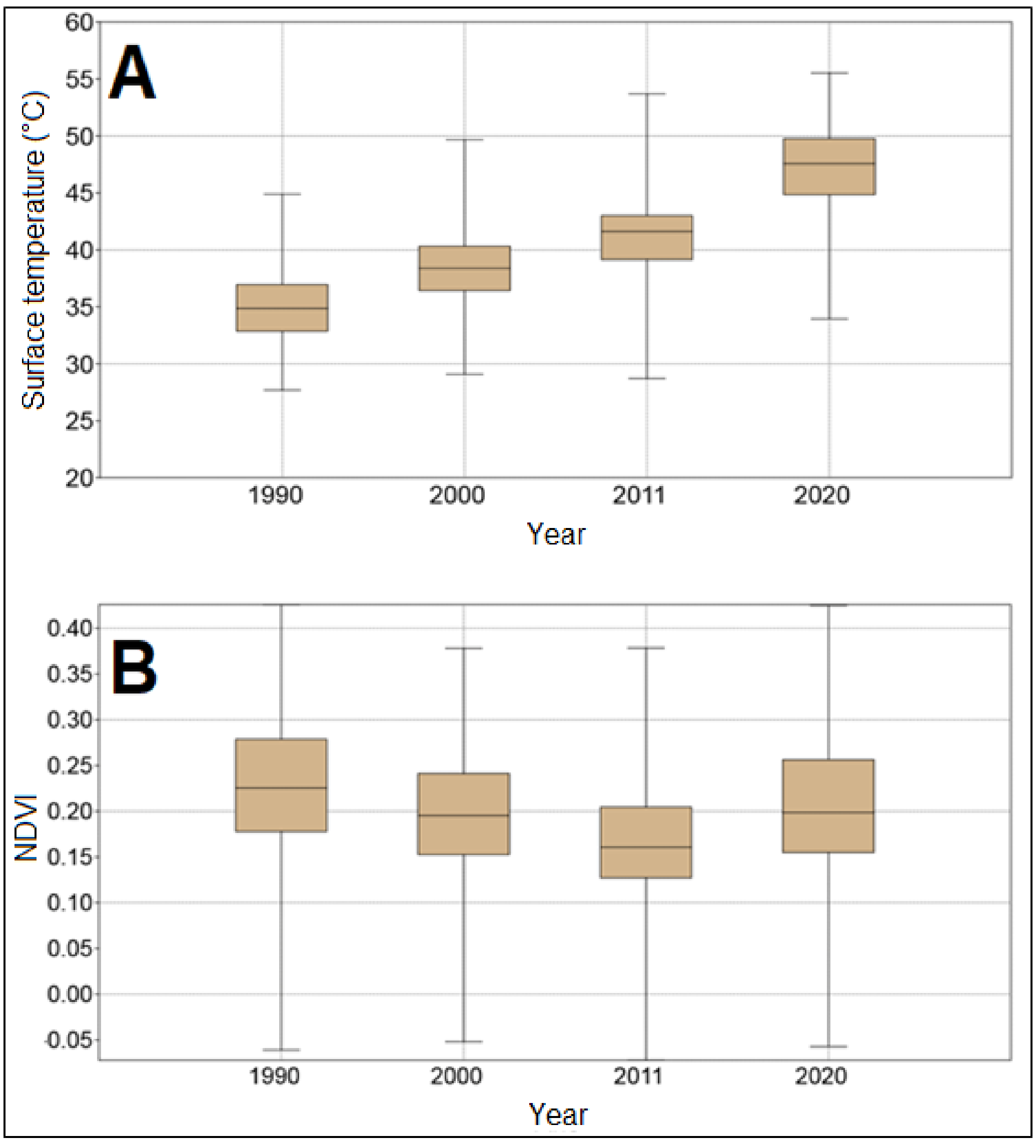


Figure 6 – Comparative Boxplot between Surface Temperature (ST) and Normalized Difference Vegetation Index (NDVI) for the different years. Panel A - Surface Temperature. Panel B - NDVI.
Source: Authors (2021).

Analyzing the results in general, the areas that presented higher temperatures were the places without primary vegetation, that is, pastures and anthropized areas. During the period studied, the average temperature values rose from 35.03 °C [34.85 °C; 35.22°C] in 1990 to 47.04°C [46.82°C; 47.26 °C] in 2020, thus expressing an increase of 10.12 °C in the average of the 30 years studied. Observing the ST and NDVI maps (Figure 4), it is noted that the surface temperature has gradually increased over the years throughout the urban area. The western region of the studied municipality does not have a large cluster of buildings, most of which are formed by pastures. However, from 1990 to 2020, the removed native vegetation influenced the increase in surface temperature throughout its surroundings. In the central region, the more urbanized area also showed increases in surface temperatures due to the use of materials with greater thermal energy storage capacity and greater absorption of solar radiation. Vianna (2018) found that the type of existing vegetation and the materials used in civil construction directly influence the surface temperature.

Figure 7 shows the correlation between surface temperature and NDVI. The Spearman correlation coefficient showed a moderate negative correlation, ranging between -0.555 and -0.465. According to Akoglu (2018), Spearman's negative correlation coefficient is considered moderate when the values vary between -0.4 and -0.6, the range in which the data are arranged.

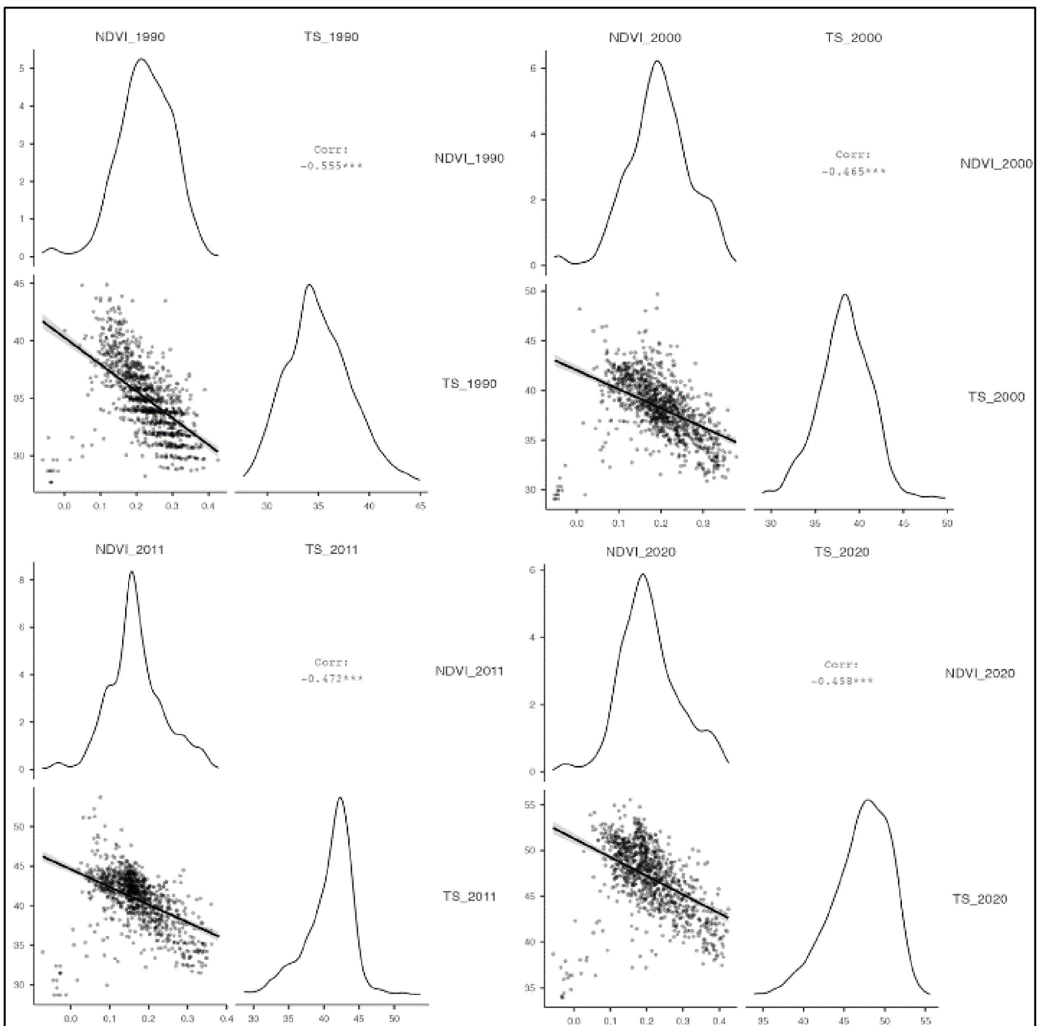


Figure 7 - Correlation between Surface Temperature (ST) in °C and Normalized Difference Vegetation Index NDVI, showing the correlation coefficients for the different years.
Source: Authors (2021).

Results shown in Figure 7 certainly did not present higher values due to the river that divides the city. It is observed that in all panels there are clustered points in the negative range for NDVI and that these points have the lowest surface temperatures. What explains this are the water values, as they have a different behavior: the river tends to have lower temperatures and does not produce photosynthetic activity, unlike other types of soil cover, where the lower the NDVI, the higher the ST.

4. Final considerations

With the results of this research, it was possible to observe that the urban microclimate generated by the urbanization process caused an increase in the surface temperature of the municipality of Ji-Paraná. The results expressed a variation of 12.01 °C in the average between 1990 and 2020. It is still possible to notice that there is a negative correlation between NDVI and temperature in the urban area of Ji-Paraná, since where the NDVI values are higher, indicating denser and healthier vegetation, the ST values are milder. This reinforces the importance of green areas for the thermal comfort of the population residing in the study area.

The temperature variation occurred mainly in the classes of pasture and anthropization, however, the causes are different: the anthropized area had as main cause its expansion and the various buildings built in it, such as buildings, houses, streets and various constructions in favor of infrastructure , schools and hospitals for example. The materials used in construction store thermal energy and transfer it to the air through convection, contributing to the increase in air temperature and consequent thermal discomfort. The pasture areas had as the main reason for the increase in surface temperature the suppression of native vegetation, which acted by attenuating the surface temperature.

Native vegetation in 2020 lost 51.49% of its previous area (1990). It is evident how the suppression of native vegetation directly interferes with surface temperature. To improve the thermal comfort of the population, it is recommended to paint roofs in light colors, preserve the APPs of rivers, buritizais, springs and preserve green areas and create new ones in strategic locations. For this, an indispensable factor is the creation of adequate and effective master plans, improving the health and quality of life of the resident population.

References

AKOGLU, H. User's guide to correlation coefficients. Turkish *Journal of Emergency Medicine*, v. 18, n. 3, p. 91-93, 2018.

ALATORRE, L. C. et al. Temporal changes of NDVI for qualitative environmental assessment of mangroves: shrimp farming impact on the health decline of the arid mangroves in the Gulf of California (1990–2010). *Journal of Arid Environments*, v. 125, p. 98-109, 2016.

ALVES, E. et al. Multitemporalidade das anomalias da temperatura de superfície: o caso da cidade de Iporá, Brasil. *Journal Of Geography And Spatial Planning*, Lisboa Pt, v. 0, n. 12, p. 5-21, 30 dez. 2017.

AMARAL, R. et al. O sequestro de carbono em trechos da floresta urbana de Belo Horizonte: por um sistema de espaços livres mais eficiente no provimento de serviços ecossistêmicos urbanos. *Paisagem e Ambiente*, São Paulo SP, v. 0, n. 39, p. 163-179, 20 out. 2017. Universidade de São Paulo, Agência USP de Gestão da Informação Acadêmica (AGUIA).

ARTIS, D. A.; CARNAHAN, W. H. Survey of Emissivity Variability in Thennography of Urban Areas. *Remote Sensing of Environment*, Nova York - Ny, v. 4, n. 12, p. 313-329, maio 1982.

ASSALVE, L. C. de Freitas et al. Índice de Vegetação (NDVI) na gestão do uso da terra na zona de amortecimento da estação ecológica de Assis - SP. *Os Desafios da Geografia Física na Fronteira do Conhecimento*, Campinas - SP, p. 5669-5673, jun. 2017. INSTITUTO DE GEOCIÊNCIAS – UNICAMP.

BASTOS, Terezinha Xavier. *O clima da Amazônia Brasileira segundo Köppen*. Belém: EMBRAPA-CPATU, 1982.

BRASIL. *Código Florestal*. Lei 12.651, de 25 de maio de 2012.

BREIMAN, L. Random forests. *Machine learning*, v. 45, n. 1, p. 5-32, 2001.

CARBONE, A. S. *Gestão de áreas verdes no município de São Paulo, SP - Brasil: ganhos e limites*. 2000. 242p. Dissertação (Mestrado em Ciências) - Faculdade de Saúde Pública da Universidade de São Paulo, São Paulo, 2014.

CARLSON, T.N.; RIPLEY, D.A., 1997. On the relation between NDVI, fractional vegetation cover, and leaf area index. *Remote Sensing of Environment*, 62, pp. 241-252.

CORDANI, U. G., MARCOVITCH, J., SALATI, E. Avaliação das ações brasileiras após a Rio-92. *Estudos Avançados* (USP. Impresso), São Paulo – SP, v. 11, p. 399-408, 1997.

DE SOUSA LEITE, A.C., DE OLIVEIRA, L.M.M., DA SILVA, B.B., MONTENEGRO, S.M.G.L., BEZERRA, U.A. Mudança Espaço Temporal do Uso e Cobertura do Solo e Estimativa da Temperatura da Superfície no Município de Teresina–Piauí, Brasil. *Anuário do Instituto de Geociências*, v. 42, n. 04, p.42-51. 2020.

DOUGLAS, C. E.; MICHAEL, F. A. On distribution-free multiple comparisons in the one-way analysis of variance. *Communications in Statistics-Theory and Methods*, v. 20, n. 1, p. 127-139, 1991.

DWASS, M. Some k-sample rank-order tests. *Contributions to probability and statistics*, 1960.

FATHIZAD, H. et al. The investigation of spatiotemporal variations of land surface temperature based on land use changes using NDVI in southwest of Iran. *Journal of African Earth Sciences*, v. 134, p. 249-256, 2017.

FEARNSIDE, P. M. Reserva de Pesquisa Ecológica para a Floresta Amazônica criada em Ouro Preto do Oeste Rondônia. *Acta Amazonica*, Manaus – AM, v. 14, n.3-4, p. 527-528, 1984.

GALLO, K. et al. Validation of satellite observations of storm damage to cropland with digital photographs. *Weather and Forecasting*, v. 34, n. 2, p. 435-446, 2019.

GIGUÈRE, M. Urban Heat Island Mitigation Strategies. *Instauré Aux Publications* Du Québec, 2009. 75 p.

IBGE. Instituto Brasileiro de Geografia e Estatística. *Estimativa Populacional* 2020, 2021. Disponível em: < https://cidades.ibge.gov.br/brasil/ro/ji-parana/panorama> Acesso: 15 de fev. 2021.

IBM Corp. Released 2019. *IBM SPSS Statistics for Windows*, Version 26.0. Armonk, NY: IBM Corp.

JI-PARANÁ (Município). *Lei nº 2187*, de 24 de agosto de 2011. Ji-Paraná, RO, 25 ago. 2011.

KAREN ZANTER (org.). *Landsat 8 (L8) Data Users Handbook*. 4. ed. Sioux Falls, South Dakota: Department of The Interior U.S. Geological Survey, 2019. 106 p.

KRUSKAL, W. H.; WALLIS, W. A. Use of ranks in one-criterion variance analysis. *Journal of the American Statistical Association*, v. 47, n. 260, p. 583-621, 1952.

MELO, E. T.; SALES, M. C. L.; OLIVEIRA, J. G. B. Aplicação do Índice de Vegetação por Diferença Normalizada (NDVI) para análise da degradação ambiental da microbacia hidrográfica do Riacho dos Cavalos, Crateús-CE. *Raega-O Espaço Geográfico em Análise*, v. 23, 2011.

ONU. Transformando Nosso Mundo: *a Agenda 2030 para o Desenvolvimento Sustentável*. Disponível em: < https://brasil.un.org/pt-br/sdgs > Acesso em: 17/04/ 2021.

PAL, M. Random Forest classifier for remote sensing classification. International *Journal of Remote Sensing*, v. 26, n. 1, p. 217-222, 2005.

PEREIRA, G. T. et al. Análise da relação entre temperatura e cobertura vegetal de área urbana utilizando sensoriamento remoto em Coxim/MS. *South American Journal of Basic Education, Technical And Technological*, v. 6, p. 42-53, 2019.

PINHEIRO, R. T.; MARCELINO, D. G.; MOURA, D. R. Impacto da implantação do BRT na arborização da região central de Palmas, Tocantins. *Desenvolvimento e Meio Ambiente*, v. 46, 2018.

QGIS.org, 2021. *QGIS Geographic Information System*. QGIS Association. Disponível em: <https://www.qgis.org/pt_BR/site/forusers/download.html>. Acesso em: 10 jan. 2021.

RAHMAD, R.; NURMAN, A.; PINEM, K. Impact of NDVI change to spatial distribution of land surface temperature (A study in Medan city, Indonesia). *In: 1st International Conference on Social Sciences and Interdisciplinary Studies* (ICSSIS 2018). Atlantis Press, 2019. p. 167-171.

RIBEIRO, L. R. A *Degradação da Mata Ciliar no Rio Salgado em Lavras da Mangabeira - CE: A Invasão Urbana e Seus Efeitos Devastadores*. Trabalho de conclusão de curso (Licenciatura em Geografia). Centro de Formação de Professores – CFP, Universidade Federal de Campina Grande, Cajazeiras, PB. 2018.

RODRIGUES, H. V. et al. Análise da qualidade ambiental da bacia hidrográfica do igarapé Dois de Abril, Ji-Paraná-RO. *Almanaque Multidisciplinar de Pesquisa*, v. 1, n. 2, 2019.

ROUSE, Jhon W. et al. Monitoring the vernal advancement and retrogradation (green wave effect) of natural vegetation. *NASA/GSFC Type III Final Report*, Greenbelt, Md, v. 371, 1974.

SANTOS, R. B. *Análise da Temperatura de Superfície Terrestre em Áreas de Pastagens com Diferentes Sistemas de Produção e Tipos de Manejo*. 146p. Dissertação (Mestrado em Engenharia Agrícola) - Faculdade de Engenharia Agrícola, Universidade Estadual de Campinas, São Paulo, 2018.

SENADO FEDERAL. *Criados critérios de classificação do espaço urbano e rural.* Disponível em: https://www12.senado.leg.br/noticias/materias/2009/10/06/criados-criterios-de-classificacao-do-espaco-urbano-e-rural#:~:text=-%20De%20médio%20porte%2C%20se%20tiver,superior%20a%20cem%20mil%20habitantes. Acesso em: 01 mar. 2021.

SHIMABUKURO, Y. E.; NOVO, E. M.; PONZONI, F. J. Índice de vegetação e modelo linear de mistura espectral no monitoramento da região do Pantanal. Pesquisa *Agropecuária Brasileira*, v. 33, n. 13, p. 1729-1737, 1998.

SIDDIQUE, N. P.; GHAFFAR, A. Spatial and Temporal relationship between NDVI and Land Surface Temperature of Faisalabad city from 2000-2015. *European Online Journal of Natural and Social Sciences*, v. 8, n. 1, p. pp. 55-64, 2019.

SOLANGI, G. S.; SIYAL, A. A.; SIYAL, P. Spatiotemporal dynamics of land surface temperature and its impact on the vegetation. *Civil Engineering Journal*, v. 5, n. 8, p. 1753-1763, 2019.

SOUZA, D. O.; NASCIMENTO, M. G.; ALVALÁ, R. C. S. Influência do crescimento urbano sobre o microclima de Manaus e Belém: Um estudo observacional. *Revista Brasileira de Geografia Física*, v. 8, n. 04, p. 1109-1124, 2015.

STEEL, R. G. D. A rank sum test for comparing all pairs of treatments. *Technometrics*, v. 2, n. 2, p. 197-207, 1960.

STEEL, R. G. D. *Some rank sum multiple comparison tests. Biometrics*, v. 17, p. 539-552, 1961.

TEIXEIRA, L. S. *Dinâmicas Territoriais em Rondônia: Conflitos fundiários entorno do Projeto Integrado de Colonização Sidney Girão (1970 - 2004)*. 152 p. Dissertação (Mestrado em História) - Programa de Pós-Graduação em História, Pontifícia Universidade Católica do Rio Grande do Sul Faculdade de Filosofia e Ciências Humanas, Porto Alegre, 2015.

TEIXEIRA, M. R. A *Utilização do Geoprocessamento na Análise Ambiental e Sua Importância na Tomada de Decisões: Um Estudo Sobre O Uso do Geoprocessamento em Pesquisas Sobre Ocupação Desordenada Do Solo*. 40 p. Pós-graduação Lato Sensu em Análise Ambiental e Desenvolvimento Sustentável - Instituto CEUB de Pesquisa e Desenvolvimento, Centro Universitário de Brasília, Brasília, 2015.

THE JAMOVI PROJECT (2021). *jamovi. (Version 1.6) [Computer Software]*. Retrieved from https://www.jamovi.org.

TURCHI, L. M. *A colonização dirigida no processo de expansão e ocupação da fronteira agrícola: território federal de Rondônia*. 1981.

USGS – U.S Geological Survey. *Science for a Changing World*. Disponível em: <https://earthexplorer.usgs.gov/>. Acesso em: 22 fev. 2021.

VIANNA, Elen Oliveira. *O Campo Térmico Urbano – Ilhas de Calor em Brasília-DF*. 2018. 267 f. Tese (Doutorado) - Curso de Arquitetura e Urbanismo, Universidade de Brasília – UNB, Brasília, DF, 2018.