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Identification of the urban heat islands phenomenon in a small city: the study case of Três Rios/RJ, Brazil

Identificação do fenômeno de ilha de calor em cidade de pequeno porte: estudo de caso de Três Rios/RJ, Brasil

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ABSTRACT

The phenomenon of urban heat islands (UHIs) is caused by an increase in temperatures in a given urban area as a result of human activities and is usually studied in medium and large cities. This study aimed to verify if the phenomenon of UHIs occurs in the city of Três Rios, RJ, a small-sized town. In this study, a mobile measurement transect was performed considering preestablished data collection points/stations. Five points were selected, including a rural area, an urban park within the city (Parque Natural Municipal), and three points within the urbanized area. The equipment used was the Brunton®/ADC PRO handheld weather station. The data collection period ranged from September 2018 to July 2019, which included the four seasons of the year. Measurements were taken at 6:00, 12:00, 15:00, 18:00, and 21:00 in alternate days during the study period. Considering the temperature measurements, two different indicators of thermal variability were used. Strong magnitude heat islands were detected taking into consideration the relevant variation of maximum temperatures observed in the urban area when compared to the rural area. The results point out that the most affected population are the ones located within urban areas, mostly individuals under socioeconomic vulnerability. The results obtained can be used as support for the development of strategies to minimize the thermal discomfort to populations exposed to the influence of higher magnitude UHIs.

Keywords: anthropogenic heat; small town; thermal magnitude; thermal anomaly.

RESUMO

O fenômeno ilha de calor urbana (ICU) consiste no aumento de temperaturas de uma área urbana e é influenciado pelo desenvolvimento de atividades antrópicas e comumente estudado em cidades de médio e grande porte. Esta pesquisa buscou verificar a ocorrência do fenômeno ICU na cidade de Três Rios/RJ, um município de pequeno porte. Para este trabalho foi estabelecido um transecto móvel de medição das temperaturas em locais com diferentes tipos de ocupação. Os pontos medidos foram: um na área periurbana, no parque municipal, e dois locais de urbanização consolidada, além de uma área rural, pontos estes para os quais foram considerados dados da estação meteorológica automática existente no município. O equipamento portátil utilizado foi uma central meteorológica Brunton®/ADC PRO. O período analisado compreendeu de setembro de 2018 a julho de 2019, englobando as quatro estações climáticas. As medidas foram realizadas às 6, 12, 15, 18 e 21 h em dias alternados dos meses em questão. Com base nas medições de temperatura, dois indicadores distintos de diferenciação térmica foram considerados, e foi possível constatar ilhas de calor de forte magnitude, considerando-se a relevante variação das máximas das temperaturas identificadas para a zona urbana em relação à zona rural. De acordo com a análise dos resultados, a população mais afetada seria a que reside na área urbanizada, sobretudo aquela em vulnerabilidade socioeconômica. Os resultados obtidos poderão servir como subsídios para a elaboração de estratégias que visem minimizar o desconforto térmico na população em áreas onde ocorreram maiores amplitudes sob influência das ilhas de calor.

Palavras-chave: calor antropogênico; região centro-sul fluminense; magnitude térmica; anomalia térmica.

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Introduction

Air temperature can be affected by the human interventions in a region, once urbanization creates a new space and shifts general environmental conditions, such as creating changes in energy flow (Fialho, 2009). Gunawardena et al. (2017) explained that the energy absorbed by urban surface is related to solar radiation and to the anthropogenic heat generated, and that its balance is established by convection and humidity evaporation processes and by the configuration of the urban environment. The impacts of urban development on energy balance can define the climate within the cities, by not just causing thermal discomfort but also affecting habitat conditions and human health (Oke, 1988). Considering this scenario, the increasing level of temperatures within urban areas can lead to the phenomenon of urban heat islands (UHIs).

The phenomenon of UHIs is characterized by an increase in temperatures in an urban area when compared to the surrounding rural areas, and this is considered a consequence of anthropogenic influence (Ward et al., 2016). Analyzing the phenomenon of heat islands, in terms of an "urban energy balance," the way energy enters and leaves a system considers that the solar radiation that enters the system is retained for a longer period on artificial surfaces when compared to natural surfaces (Oke, 1988; Gartland, 2010; Gunawardena et al., 2017). The formation of UHI is influenced by several factors, such as the reduction in wind circulation, as a consequence of tall buildings; atmospheric pollution; reduction in tree cover; reduction of humidity rates; and the emission of particles (Yow and Carbone, 2006).

While the spatial configuration of cities can alter the energetic balance in a way that heat is retained, in rural areas, heat absorption is lower and the dissipation of solar radiation is more efficient. This is stimulated by the constant wind flow and vegetation cover, which naturally absorbs less heat and contributes to the increase in air humidity through evapotranspiration (Gallo et al., 2019). Moreover, the highest cover of permeable surfaces on natural spaces allows water infiltration, which contributes to the process of evaporative cooling (Gartland, 2010; Santos et al., 2012; Oliveira et al., 2018).

Studies on the relationship between the urban climate and human health found an association of thermal stress to pollution, thereby affecting children, elderly, and people in socioeconomic vulnerability with chronic disease (Gabriel and Endlicher, 2011; Scherer et al., 2013; Larsen, 2015). Also, studies pointed to the spread of infectious diseases as a consequence of climatic conditions of the cities (Munyuli et al., 2013; Ribeiro et al., 2016). According to the previous report published by the Intergovernmental Panel on Climate Change (IPCC, 2014), which examined the negative effects of UHI on the population, this phenomenon might aggravate and become more frequent in a near future. Considering this, Viegas et al. (2013), Dhar and Khirfan (2017) and Jiang et al. (2017) discussed the importance of evaluating and identifying UHI when making decisions about plans and adaptation projects regarding the impacts of urbanization and climate change and their mitigation.

Yamashita (1996) reported the occurrence of UHIs in Tokyo and concluded that these UHIs remained constant in the summer but presented thermal variation in the winter in different areas, reaching differences of 5°C. Montávez et al. (2000) showed that in the city of Granada (Spain), densely developed areas presented intense UHIs, showing an increase in temperature of up to 3°C when compared to the rural areas. In contrast, this same study registered a decrease in temperature of up to 1°C in a specific region, associated with the buffer effect of an urban park.

A study involving 397 global cities, between 2001 and 2007, considered the differences between urban and rural temperatures. This study pointed a significant variation in the intensity of temperatures of the cities with 42.1% for day time and 30.5% for night time (Yao et al., 2019). Vegetation was also pointed by the authors as an important factor driving differentiation between day and night times in rural areas, as it causes a lower variation in temperature. Amorim (2012) analyzed the variation in temperature during the day, taking into consideration the urban–rural configuration in the city of Presidente Prudente, SP, and observed that in the first hours of the day, the solar energy reaches the land surface in an inclined degree, which creates a "shade effect," making it difficult for solar rays to penetrate on the urban structure. Whereas in environments with sparse rural buildings, the transformation of solar energy from short to long waves happens more quickly, generating warmer environments.

Because of their magnitude, studies on UHIs are usually made on medium or big cities, such as Brasília (Vianna, 2018), Presidente Prudente — SP (Amorim, 2012), Belo Horizonte — MG (Almeida and Abreu, 2010), and Goiânia — GO (Nascimento and Oliveira 2011), in Brazil. Nowadays, some studies on the theme have also been published for small cities (i.e., cities with < 100,000 population), such as Ilha Solteira — SP (Romero, 2016) and Iporá — GO (Alves, 2016), and those have applied different methods.

Some of the methods used to analyze the effect of urbanization include geotechnical analyses, fixed-base weather stations, and mobile transects. Romero (2016) used images from the satellite Landsat 8/TIRS and found UHIs of weak and medium magnitudes, following the UHIs indicators proposed by Garcia (1996). Even though this is an effective method to visualize temperatures of large areas, the satellites that provide the images do not record continuous information along the day, as they are constantly moving around the Earth (Gartland, 2010). Other than the limitation in providing images, it is also necessary to choose proper images, with clear days and few levels, for better analyses, as the visualization of satellite images can be affected by atmospheric conditions.

Alves (2016) collected data on air temperature and humidity using two fixed-base weather stations in urban and rural areas and found that UHI intensity varied between 0.5 and 3.5°C. The fixed-base weather stations method is the simplest method for analyses of UHI effects. However, there are not always enough weather stations in the target areas and the position of weather stations might bias the results. The possibility of installing temporary weather stations might be unfeasible due to financial and logistical limitations (Gartland, 2010).

Considering the limitations of satellite images and fixed-base weather stations, mobile transects are an alternative method for the evaluation of UHIs. In this method, data collection points are preestablished along transects, and then data are collected with the use of portable equipment, such as a portable thermohygrometer. Studies developed with the use of mobile transects (Silva et al., 2018; Sun et al., 2019) found important information and had relevant results involving the identification of heat islands. However, these studies were completed in a period of days within one season and did not cover longer periods of time, which would be ideal to describe and identify heat islands and their patterns.

This study brings out a novel approach to identify heat islands using the mobile transects method in the city of Três Rios, a small city that had a considerable increase in urbanization rates in the past 10 years. The city of Três Rios is in a naturally hot and dry region, which has presented progressive discomfort caused by high temperatures, as reported by the population.

A second novel aspect of this study is the time frame of data collection; meteorological data were collected in a whole year, on specific times of the day. The analyses covered all four seasons, which allowed a complete and consistent analysis of the studied phenomenon.

The objective of this study was to verify the occurrence of UHI in the city of Três Rios, considering the analyses of differences in temperatures between rural and urban areas.

Materials and Methods

Study area

The city of Três Rios (Figure 1) is located in the central south region of the state of Rio de Janeiro. Its territory covers an area of 322.843 km^2 and it has a population of 81,804 habitants (IBGE, 2015). Its proximity to the three largest consumer centers of the country (São Paulo, Rio de Janeiro, and Minas Gerais), its water availability, and its government program of tax exemption attracted the industry sector to the city in the past 10 years, speeding the process of urbanization.

About 97% of the habitants in the city of Três Rios live in the urban zone, which has a territorial area of about 28 km^2; 88% of this area is classified as densely urbanized, and 12% with low urbanization (IBGE, 2015). Densely urbanized areas contain land with continuous occupation, constructions very close to each other, normally composed of buildings without outdoor areas or with small backyards (IBGE, 2017).

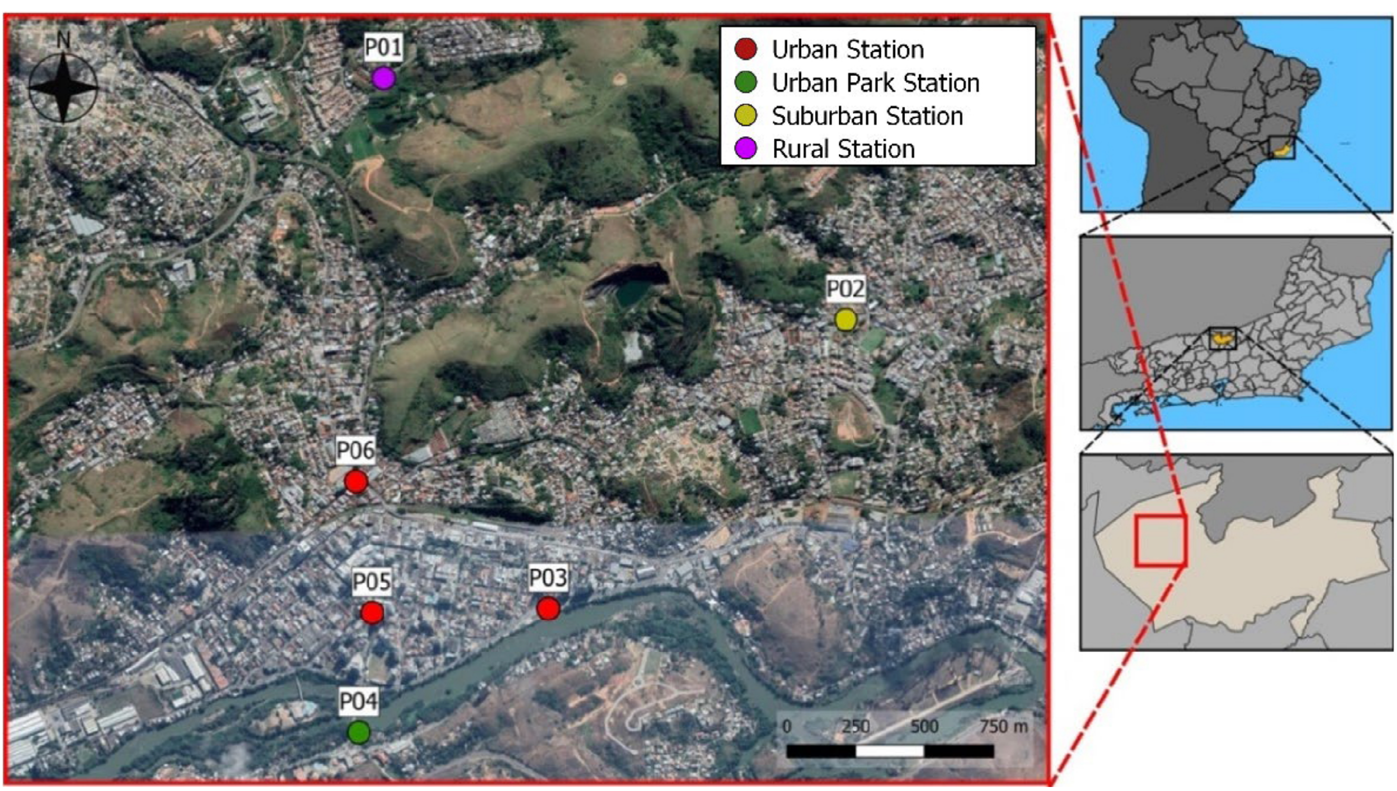

Figure 1 – Location of measurement points in the city of Três Rios/RJ.

The city is located in the unit of ridge alignments of the Paraíba do Sul river with morphological forms separated by mountain ranges and from 300 to 800 m. Some important mountain ranges in the region are the hilly areas such as Alto da Terra Seca, Retiro, and Cavaru; in these examples, the topography ranges from 200 to 400 m and the hills are shaped with ample round tops and moderate slopes with amplitude inferior to 100 m (Valladares et al., 2012; COHIDRO, 2016). Because of the presence of hills, the land urban occupation in the city is mostly focused in the valleys, which tend to be the flooding areas.

When it comes to climate, the city of Três Rios is in the subtropical humid zone, presenting cold dry winters and warm wet summers. The mean annual temperature is 22°C, the warmest month is February, with historic mean temperatures of 25.5ºC, and the coldest month is July, with mean temperature of 18.4ºC. Mean annual precipitation is 1592 mm, with most precipitation happening from November to January, and the driest period is from June to August (Alvares et al., 2013).

The city of Três Rios has low wind frequency, with mean speed of 1.90 m/s, during almost all year, with exception of August to October, when the predominant direction is Northeast. The highest wind intensities occur during the Spring and lowest during the Fall (INEA, 2015).

Fieldwork

To understand the dynamics of the urban climate in the city of Três Rios, air temperature was monitored between September 2018 and July 2019, using mostly the method of mobile transects. The measurements encompassed the four seasons of the year in the city of Três Rios. The periods of weather instability (rain and weather fronts) were disregarded during analysis, to avoid bias.

The mobile transects method consists of covering preestablished routes in order to obtain data points about locations along the routes with the use of meteorological portable equipments. Spronken-Smith and Oke (1998) noted that in small study areas, it is possible to cover the region with the use of a bicycle. Among the negative sides, Gartland (2010) points out the impossibility of collecting data from different locations simultaneously.

The temperature measurements were taken on five collection points in a preestablished circuit. Temperature data were also collected from a weather station in the city. The measurement points were as follows: P01, weather station located in a rural area; P02, located in a suburban area; P04, located in the Natural Municipal Park of Três Rios (i.e., urban park), and points P03, P05, and P06, which were located in the urban area. P03 and P04 are located in the Paraíba do Sul river's buffer zone, while P05 and P06 are located in the oldest urban area within the city, which has high vehicle traffic and dense land occupation. The locations of measurement points are presented in Figure 1 and Table 1.

The measurements were done considering the urban canopy, which is characterized as the ideal location to measure temperatures of heat islands. Measurements were taken 1.50 m from the soil surface, which comprises the volume below the tops of buildings and trees (Gartland, 2010).

Table 1 – Measurement points within the city of Três Rios/RJ, including type of area, coordinates, and elevation.

ID	Type of area	Coordinates UTM (WGS84) (m)		Elevation (m)
P01	Rural	684794.0	7555182.0	305
P02	Suburban	686437.7	7554200.7	278
P03	Urban	685347.3	7553091.3	269
P04	Urban park	684653.6	7552616.0	270
P05	Urban	684707.6	7553082.0	274
P06	Urban	684654.7	7553592.8	279

An ADC PRO summit (handheld weather station Brunton®) was used to measure air temperature. For better accuracy, equipment calibration was done weekly and/or when weather conditions were altered. P01 (Três Rios weather station-A625), the fixed weather station operated by the National Institute of Meteorology (INMET), was used as a reference for alterations in weather conditions. P01 is located in the rural area of the Purys neighborhood.

A bicycle was used for moving along the mobile transect. The bicycle was a solution to avoid traffic jam, reducing delays on the measurement times. Data collection was performed at 06:00, 12:00, 15:00, 18:00, and 21:00 considering a 1-min cool down for equipment stabilization. Moving along transects and running the whole circuit took about 40 min, which is in accordance with Araujo et al. (2010), that recommends a maximum of 1 h for the duration of a measurement circuit in mobile transects. Collections were interspersed each three days during the measurement period.

Measurement times were selected based on the energy entry and dissipation flux (i.e., solar radiation) through the city as well as atmospheric and human activities. Also human activities were considered, including the density of constructions, geometry of streets, population size, and intensity of flux of vehicles and paving (Fialho, 2009). For morning measurements, 06:00 h was the time chosen since this is the time with lower urban movement within the city and low incidence of solar radiation. The 12:00 h measurement represents the period of higher incidence of solar radiation. The 15:00 h measurement was chosen based on strong solar radiation incidence and energy retention in the atmosphere, which is influenced by land use and urban movement. The 18:00 h measurement was influenced by rush hour and the consequential increase in vehicle traffic. The 21:00 h measurement, after sunset, was chosen based on the influence of thermal emissions from urban constructions and possible presence of relevant magnitudes of anthropogenic heat (Oke, 1988; Fialho, 2009).

In total, this study included 505 field campaigns for air temperature measurement, during 11 consecutive months, totaling 3030 measurements in a period that included the 4 climatic seasons of the year.

Indicators of thermal differentiation

Magnitude of heat islands

Two indicators of thermal differentiation based on temperature measurements were considered. The first method is the calculation of the magnitude of heat islands or freshness islands adapted from Garcia (1996). Considering magnitudes as the difference between mean temperatures in the urban and rural areas, Garcia (1996) proposed magnitude degrees to characterize intensity levels of heat islands; positive numbers indicate heat islands, negative numbers indicate freshness islands. This approach assumes that the rural area incurs lower influence of urbanization, and therefore, this area is considered a reference to indicate the impacts caused by urban occupation on the temperatures.

This study's indicators differed from the ones considered by Garcia (1996), as in this study, not only the differences between mean temperatures of rural and urban areas were considered. Here the temperatures on each collection point were computed from the mean values obtained from the reference point, that is, the rural area, P01. This approach was used taking into consideration that the number of collection points for each type of area (urban, suburban, urban park, and rural) was small, so comparing means and running statistical analysis would not be representative of the land use classes, as areas had a sample size of one experimental unit. Also, calculating the magnitudes for each point would allow a higher spatial differentiation of thermal differences. Equation 1 represents the expression for the thermal magnitude.

$$M_{i,n} = T_{i,n} - T_{0,n} \quad (1)$$

Where:

$M_{i,n}$: the UHI magnitude on collection point *i* in the *n* moment;
$T_{i,n}$: the temperature of point *i* in the *n* moment;
$T_{0,n}$: the temperature of point 0 (rural) in the *n* moment.

Thus, different magnitudes were calculated for each point that was not P01. After the magnitude was calculated, a categorization of results was made based on the intensity levels proposed by Garcia (1996), as presented in Table 2.

Table 2 – Intensity degrees of freshness and heat islands according to calculated magnitudes.

Magnitude (°C)	Category	Intensity
< -6	Freshness island	Very strong
-6 to -4		Strong
-4 to -2		Moderate
-2 to 0		Weak
0 to 2	Heat island	Weak
2 to 4		Moderate
4 to 6		Strong
6		Very strong

Source: Garcia (1996, p. 285).

Thermal anomalies

The second indicator to evaluate thermal differentiation is the calculation of thermal anomalies for each point, following the method used by Alves (2016) and Alcoforado and Andrade (2006). This method is calculated using the standardized scores that consider the mean temperature of a specific time and the standard deviation of the mean. Equation 2 represents the expression for the calculation of this indicator.

$$A_{i,n} = \frac{T_{i,n} - \underline{T_n}}{\sigma_{T_n}} \quad (2)$$

Where:

$A_{i,n}$: the thermal anomaly in the moment *n* and at the point *i*;
T_n: the mean temperature in the moment *n*;
$T_{i,n}$: the temperature of point *i* in the moment *n*;
σ_{Tn}: the standard deviation of temperatures in that moment.

The reference for the evaluation of thermal anomalies is not the temperature of a specific area, as it was for the measurement of magnitude, but it is the mean temperature of all points.

Data analyses

For a better visualization and description of the variations of the phenomenon for different time periods, data were subdivided in two ways: one considering the four seasons of the year, and the other considering the different times of the day. Following the subdivisions, the results for temperature, magnitude, and anomalies were analyzed using descriptive statistics (e.g., means, standard deviations, median, frequency analysis, and quartiles) and boxplot graphics, which represent the distribution of results. This type of graphic was chosen as it presents the values of most interest for the research, that is, extreme and central values. Iversen and Gregen (1997) and Montgomery and George (2003) supported the use of boxplot for these purposes. These authors explained that boxplots are strong tools for the comparison of data divided in groups, such as the data included in this study, which were grouped into three categories: occupation, time, and season.

Outliers were removed to avoid bias. The reference for outlier removal was based on the method suggested by Montgomery and George (2003), which is considered as criteria for the removal of the values that were higher than the sum of the third quartile with 1.5 times the interquartile interval or smaller than the subtraction of the first quartile from 1.5 times the interquartile interval.

Statistical analyses and figures were obtained using RStudio v. 1.2.5042, based on the R language R v. 3.6.1. Following these methods, discussion was made based on the frequency, intensity, and variability of thermal differentiation among the collection points and conclusions were elaborated.

Results and Discussion

The temperatures ranged between 7.2 and 37.8°C, with mean temperature of 24.3°C, at the rural point P01; at P02 (suburban point), the values ranged between 6.3 and 39.1°C, with average of 24.5°C; and at P04 (urban park), the range was between 6.3 and 40.6°C, with mean of 24.4°C. At the urban points, the values ranged between 6.6 and 40.4°C at P03, between 6.6 and 40.1°C at P05, and between 6.0 and 39.4°C at P06, with average temperature of 24.6°C.

Figure 2 includes the daily means by land use types. It is possible to observe situations in which the means are lower for the rural area (less impacted by urbanization) and higher for the other type of areas.

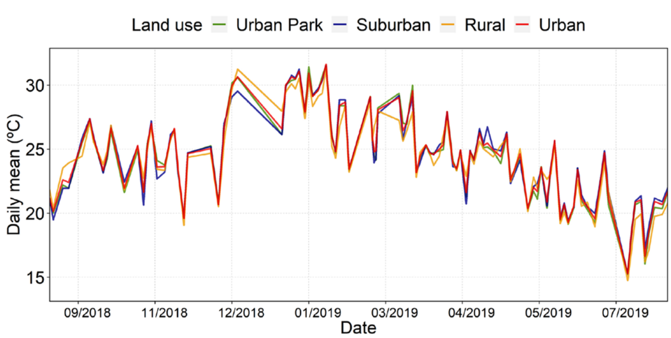

Figure 2 – Mean daily temperatures by land use types.

Analyses of results for temperature

The boxplots presented in Figure 3 include the distribution of temperatures during the different times of the day for the entire series of data (102 days). From these results, it is observed that the temperatures were generally lower around 06:00, with an increase during the day, reaching maximum values around 15:00, and after this time of the day, the temperatures decrease.

Table 3 presents minimum and maximum temperatures observed, as well as their amplitude (difference between maximum and minimum values, considering all points and the entire monitoring period) by time of measurement. The lower amplitude (considering all points and the period analyzed) happened at 06:00, with value of 18.6°C. Following that, the highest amplitudes were found at 15:00 (21.8°C), 18:00 (20.3°C), 12:00 (19.4°C), and 21:00 (17.3°C).

The values between the base and the top of the block represent 50% of the boxplot data, and the distance between the two limits can be considered to establish a measure of dispersion, related to variability. For this analysis, it is observed that the smaller box occurs for the time of 06:00, with a difference of 3.60°C, indicating that this was the time with smallest variability, followed by the times of 21:00, 18:00, 15:00, and 12:00, which presented differences of 4.38, 5.10, 5.40, and 5.92°C, respectively. That way, the highest intensities happened on the times of solar irradiation, representing the influence of this variable on the temperatures, as observed by Capelli de Steffens et al. (2001).

The boxplots in Figure 4 present the distribution of results for the entire data series, similar to what was previously presented, but instead of time of the day, data were looked by season (considering all times). From these data, it is noted that the lowest temperatures occurred in

Table 3 – Minimum and maximum temperatures and the amplitudes observed by time of measurement (considering all points).

Time	Minimum temperature (°C)	Maximum temperature (°C)	Amplitude (°C)
06:00	6.0	24.4	18.6
12:00	18.2	37.6	19.4
15:00	18.8	40.6	21.8
18:00	14.8	35.1	20.3
21:00	11.4	28.7	17.3

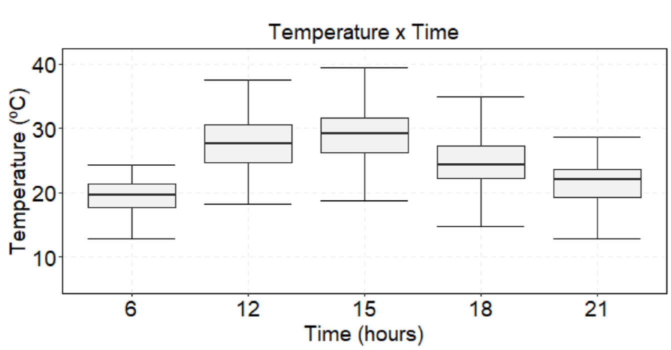

Figure 3 – Boxplots including temperature variation by time of the day.

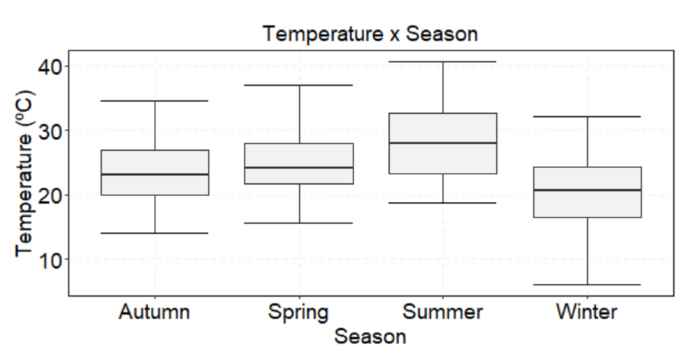

Figure 4 – Temperature boxplots by season of the year, including median values.

the winter, followed by autumn, spring, and summer. When analyzing amplitudes, the highest occurred in the winter (26.2°C), and the lowest occurred in the autumn (20.6°C), followed by summer (21.9°C) and spring (23.7°C). This agrees with what was stated by Fialho (2009) about highest variations in temperatures occur in the winter, as it is the driest season in the studied region.

The differences between the first and the third quartiles were of 7.85°C in the winter, 7.1°C in autumn, 6.1°C in the spring, and 9.3°C in the summer. Thus, even though winter amplitude was higher than the other seasons, the highest dispersion (size of the box) happened in the summer, season in which solar irradiation is more intense.

Thermal magnitude indicator

Thermal magnitude indicators varied from -8.2 to 7.6°C at P02, from -8.0 to 5.7°C at P03, from -8.0 to 5.5°C at P04, from -7.8 to 5.8°C at P05 and -8.2 to 6.0°C at P06. An analysis of frequency of the UHI intensity categories for each point of collection was done, without the removal of outliers, and is presented in Table 4.

For all points, more than 50% of measurements presented weak heat island, that is, temperatures up to 2°C higher than the temperature at the rural area P01. Considering all points in urban areas (P03, P05, and P06), more than 5% presented moderate heat island. Points P02 and P06 presented very strong heat islands, with three occurrences at P02 and one at P06. In all points, freshness islands occurred in less than 35% of the measurements.

Thus, the indicator of thermal magnitude points to a thermal differentiation between the rural area (P01) and the other types of land use for most of the measurement period with predominance of heat islands of weak intensity. These observations are in accordance to what was exposed by Sun et al. (2019) and Rodríguez et al. (2020), which pointed that weak heat islands are common in small cities. The points in urban area presented lower frequency of freshness islands than the suburban (P02) and urban park (P04) points. Among the urban points, P03 presented the highest frequency of weak and moderate heat islands; however, P06 was the only one that presented very strong intensity of heat island. Another relevant observation is that the suburban station (P02) presented the highest magnitude value and also the highest frequency of very strong heat islands. Figure 5 presents boxplots for the magnitude results by time of day and season.

The boxplots for urban points only presented positive values at the second quartile, which means that, for all conditions considered, at least at 50% of the time the temperature of the urban area was higher than the temperature of the rural area. The same pattern is observed for the suburban area, except for the 06:00 in the spring and autumn seasons. At the urban park, it is observed a high frequency of values around zero or negative for the second quartile: at 15:00 in the winter; 06:00 in the autumn, summer, and spring; and 18:00 in the spring.

When looking at 18:00 in the winter, for all points, the second quartile presented values > 2, which means that in at least 50% of times it was observed the occurrence of heat islands of moderate intensity during this time at this station.

Thus, the magnitudes with predominant positive values, and higher frequency of heat islands than freshness islands, indicate that there is thermal differentiation between the urban, suburban, urban park, and rural points. The frequency analysis showed the predominance of weak heat islands; however, moderate and very strong heat islands were also observed. Moderate heat islands were observed mostly during the winter at 18:00.

The four occurrences of very strong intensity happened on February 9, 2019 (summer) at 15:00 at P02 and P06, on April 27, 2019 (autumn) and June 29, 2019 (winter) at 18:00 at P02. These data are outliers, which means they are not representative of the average series of data. Still, extreme temperatures can become more frequent and have impacts on the well-being and health of the population, as described in several studies (Akhtar et al., 2016; Misslin et al., 2016; Brousse et al., 2019).

Table 4 – Number of occurrences (N) of the heat and freshness islands intensity categories and relative frequency (%) for the period of monitoring.

Intensity		P02 (Suburban)		P03 (Urban)		P04 (Park)		P05 (Urban)		P06 (Urban)	
		N	%	N	%	N	%	N	%	N	%
Freshness island	Very strong	1	0.20	3	0.59	1	0.20	1	0.20	1	0.20
	Strong	7	1.39	11	2.18	10	1.98	7	1.39	5	0.99
	Moderate	30	5.94	18	3.56	17	3.37	18	3.56	20	3.96
	Weak	129	25.54	89	17.62	155	30.69	117	23.17	122	24.15
Heat island	Weak	307	60.79	337	66.73	293	58.02	323	63.96	318	62.97
	Moderate	24	4.75	40	7.92	24	4.75	30	5.94	34	6.73
	Strong	4	0.79	7	1.39	5	0.99	9	1.78	4	0.79
	Very strong	3	0.59	0	0.00	0	0.00	0	0.00	1	0.20
Total		505	100	505	100	505	100	505	100	505	100

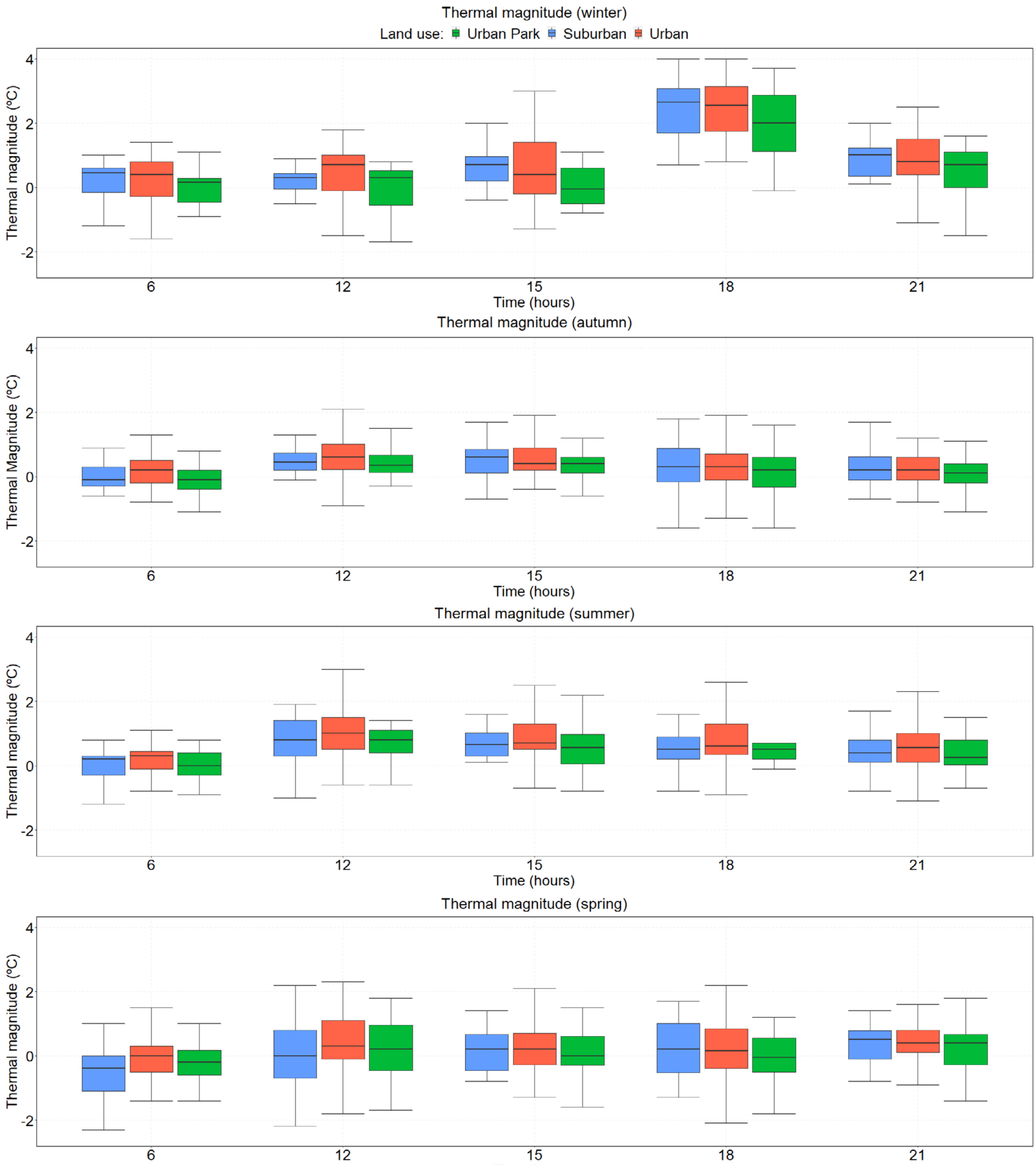

Figure 5 – Boxplots including magnitude by time of the day and season.

Thermal anomalies

Thermal anomalies are presented in Figure 6. The results show that for the rural point, the second quartile has negative values for all subgroups, with the exception of 06:00 and 18:00 h in the spring. The negative second quartile means that, in at least 50% of the observations, the temperatures in the rural point were lower than the mean of all collection points. Also, negative values were observed for the third quartile at the rural point, for 18:00 and 21:00 h in the winter; 12:00, 15:00, and 18:00 in the summer; and 12:00 h in the autumn, indicating that at these subgroups, in at least 75% of the observations, the temperatures

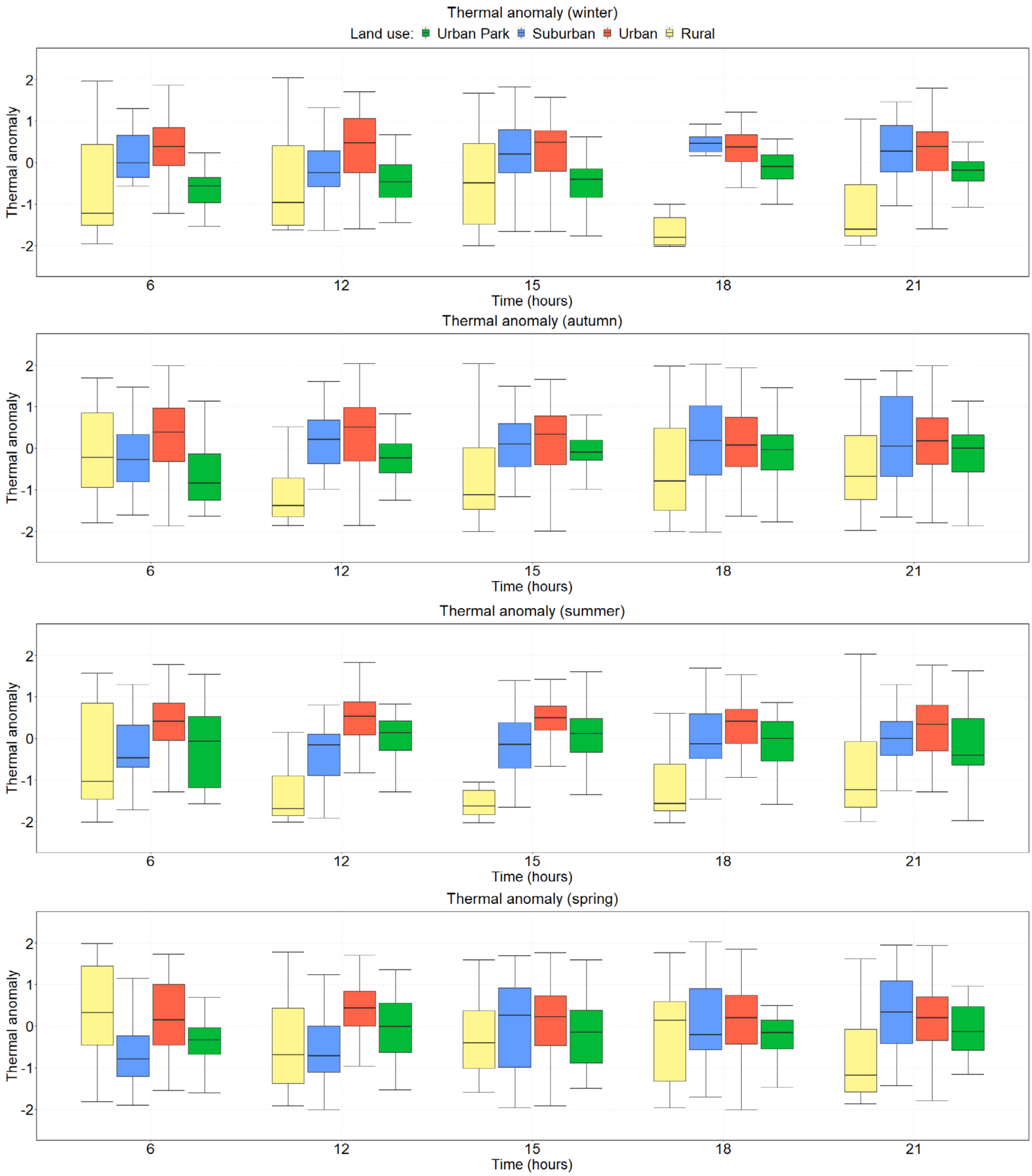

Figure 6 – Thermal anomalies by collection point, season, and time of the day.

at the rural area were lower than the average. When looking at the rural point, the 06:00 time point in the spring presented higher values than the other points at the second and third quartiles.

At the urban points, the second quartile values are higher than the ones for the other collection points in most times of the day, followed by suburban and urban park points. In addition, when looking at patterns of different times, there is a trend that the urban park and suburban areas behave similarly to the urban areas as the day goes by.

The suburban point presented the second quartile values lower than the rural point at 06:00 and 12:00 in the summer and spring, seasons with higher intensity of solar irradiation. This might be an indicator of the sun's influence and the reduction of humidity on these spaces.

A pattern of dispersion was not identified for the rural area, as the differences between the second and third quartiles can be big when compared to the other collection points and, in some cases, they can be very small.

Predominant negative values for thermal anomalies at the rural station and higher values for the urban stations indicate that there is thermal differentiation between the urban and non-urban areas in Três Rios. The urban park and suburban points presented, in most cases, values for the indicators of thermal differentiation that were lower than the ones obtained at the urban points. This observation indicates that the heat islands tend to be less intense at the points P04 and P02. The urban park (P04) is the only space around the downtown area of Três Rios with substantial tree cover and the heat islands might be lessened in this area due to the contribution of the vegetation cover to the maintenance of lower temperatures in this region. The suburban area (P02) is characterized by less intense urbanization when compared to the urban area, thus the impacts on microclimate are less intense.

However, the differences between suburban, urban park, and urban areas are not very big, following the categories proposed by Garcia (1996). Still, very strong heat islands were identified at P02. Thus, it is possible that the process of urbanization might be causing impacts on the microclimate of the suburban area and the urban park even if in low intensities. At the suburban area, the impacts are likely a consequence of the density of urban occupation, while at the urban park, this process might be related to what was described by Andrade et al. (2016), in which the fragmentation of a habitat can be drastically affected by the external environment and the humidity from the river was added to the evapotranspiration, all these were not the enough factors to provide freshness islands in this area.

As a caveat, it is important to mention that the rural point is close to surrounding urban areas, so it is also under the influence of the impacts caused by urbanization, but in less intensity if compared to the urban and suburban areas included in this study. It is possible that these impacts reflected on the results.

Thus, the results indicate the occurrence of heat islands in Três Rios potentially caused by urban densities in the city, which have been increased in the recent past years. The UHIs might also be related to the low vegetation cover in the urban area (Santiago and Gomes, 2016).

In contrast with cities from developed countries, where the growth rates are limited or inexistent, cities in developing countries, such as Brazil, can use the intensities of UHIs to guide urban planning (Zhou et al., 2017). Therefore, this study brings attention to the importance of UHIs on the public management of cities. We recommend that the issue is considered, studied, and monitored moving forward.

Três Rios is still considered a small city, although it is going through an intense process of growth. Thus, if prevention is not applied to the public management during the growth process of the city, the impacts indicated in this study can become aggravated in the future, resulting in negative effects on the health and well-being of the population.

Conclusions

In face of the results presented, this study is relevant as it introduces the existence of initial state UHIs in the city of Três Rios. This can be considered by the government and public management to guide urban development applying preventive measures. Such measures could include the increase in urban trees and afforestation of surrounding conservation areas affected by constant burns.

There is a need to sustainably plan the growth and development of the city, adopting preventive measures, inhibiting the increase in vertical buildings, and considering from an orderly and contiguous growth.

It is important to highlight the social aspect of this study, considering that the population most affected by the impacts of UHIs is concentrated in central and suburban areas and therefore establishing the importance of creating public policies that consider, above all, those who are in greater socioeconomic vulnerability.

The fact that the research was developed within a large time frame was interesting, as it allowed the observation of the variability of the phenomenon in the city, which is not common in other studies published on the theme.

This study had a limitation related to the number of collection points observed, which complicated the analysis of the spatial influence of the phenomenon. We suggest that future studies include more collection points representing each type of area, considering also more variables other than temperature.

Contribution of authors:

Silva, Y.M.N.: Conceptualization, Data curation, Investigation, Formal analysis, Methodology, Validation, Visualization, Writing — original draft, Writing — review and editing; Silva, H.M.: Conceptualization, Data curation, Formal analysis, Methodology, Software, Validation, Visualization, Writing — review and editing; Silva, R.D.A.: Data curation, Formal analysis, Software, Writing — review and editing; Marques, E.D.: Supervision, Validation, Visualization, Writing — review and editing; Gomes, O.V.O.: Funding acquisition, Project administration, Resources, Methodology, Supervision, Visualization, Writing — original draft, Writing — review and editing .

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