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Analysis of heat island intensity in a medium-sized city with a tropical climate

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ABSTRACT
The city of Cuiabá-MT continues to show demographic growth (IBGE, 2022), accompanied by urban expansion with urban planning regardless of climate issues, which contributes to generating negative socio-spatial impacts, in addition to impacting human health. This scenario has been taking shape over the years, as the urbanization process progresses, freeing itself from environmental assets, vegetated areas are being lost and the impermeable surface increases. Given this context, the general objective of this article was to analyze the spatial dependence of the urban heat island in relation to the characteristics of land use and coverage. To measure the intensity of the urban heat island, records from mobile transects and the reference station considered “rural station” were used. Analyzing the behavior of the heat island in the summer and winter seasons, it was observed that in summer the intensity of the heat island is clearer, with an average intensity of 4.70 °C , which may be associated with a decrease in permeable coverage and increased waterproof coverage. However, the island of coolness observed in the transects was more evident during winter with an average intensity of -4.26°C, highlighting that areas under the influence of large masses of vegetation had their own characteristics with different microclimates to other areas of the city. The application of geostatistics, especially the use of semivariogram, proved to be satisfactory in data analysis, demonstrating moderate to strong spatial dependence between the variables.

Keywords: Urbanization. Urban climatology. Geostatistics.

1 INTRODUCTION

In the 6th report released by the Intergovernmental Panel on Climate Change – IPCC (UNEP, 2022), researchers state that the anthropogenic influence on the warming of the earth is undeniable, causing increasingly dangerous and widespread disturbances in nature, in addition to seriously impacting the lives of billion people, despite efforts to reduce its effects.

Furthermore, there are health inequalities, especially in developing cities, which are further exacerbated by urban warming, such as heat waves, extreme precipitation, inland and coastal flooding, landslides, droughts, increased aridity, water scarcity and pollution donate. In the case of Brazil, the socio-environmental impacts of climate change are worsened due to social issues.

In this context, challenges involving the climate and infrastructure of cities are related to the built environment (thermal comfort), since high temperatures and strong solar radiation cause indirect impacts on the population's cardiorespiratory health. In this sense, strategies are emphasized as responses to current and future climate extremes in the urban context, such as the mitigation of Urban Heat Islands (ICU) based on strategies aimed at cooling (EMMANUEL,2016).

The Urban Heat Island is defined as the difference between the temperature measured in an urban space in relation to its surroundings (COHEN et al., 2012). As cities become increasingly urbanized, there is a need to integrate climatology into urban planning processes and understand the processes involved in local urban climate (ALCHAPAR et al. 2016).

According to Oke (1978), urban climate can be defined as the result of changes caused by urbanization processes on the earth's surface and by the disturbance of urbanization in the atmospheric characteristics of specific locations.

In this way, cities generate their own climate due to the interference of all the factors that occur in the urban boundary layer, that is, the layer between the ground and the upper limit, in relation to the average height of buildings. Comprising the microscale, which represents the climate of small areas around buildings, trees and roads, extending from 1m <X<1km. Therefore, the construction of new elements affects existing microclimates and creates new and more complex microclimates, which are associated with the geometry, density and functionality of the building, and the impact of these elements on the increase in air temperature, due to the heating of urban surfaces. , due to the type of materials used in buildings and ground cover, artificial surfaces absorb more heat from the sun than natural vegetation (MONTEIRO, 1976; GARTLAND, 2010).

Due to the thermal complexity present at the intra-urban scale, obtaining thermal comfort in open areas requires a delicate balance between land use and occupation and local, regional and global climatic factors. In other words, the geometry of buildings and the landscape layout have a direct impact on the amount and distribution of energy available (short and long waves) for thermal exchanges between surfaces and the atmosphere. (OKE et al., 2017).

Thus, much still needs to be done to mitigate the effect of ICU, studies indicate that the adoption of climate-sensitive urban planning is a key facilitator of adaptation to climate change, especially in cities with a demand for cooling and a tropical climate (EMMANUEL, 2016; HUNG et al., 2006; ROTH, 2007), as is the case in the municipality of Cuiabá/MT/Brazil.

Therefore, it is necessary to understand how the spatial distribution of the ICU in relation to the different soil covers behaves, that is, the influence of the city's urban fabric on the increase in air temperature.

In view of this, Vendrusculo and Carvalho (2004) report that the semivariogram is an important tool for the quantitative representation of the spatial and temporal variability of a given variable, being the most suitable for measuring spatial dependence. The various research carried out on this topic proves the efficiency of this procedure, providing support for new protocols, specifically those to be used by urban planners in making decisions related to mitigation strategies for the effects of ICU.

The Metropolitan Region of Vale do Rio Cuiabá/MT (RMVRC/MT), a territory inhabited by almost one million people, is known for its climate severity, with maximum air temperatures above 36°C. Faced with such a critical scenario, an analysis of the spatial variability of soil cover and ICU was carried out, specifically in the city of Cuiabá/MT. With the objective of identifying the spatial correlation between land cover variables and ICU in the winter and summer seasons.

2 MATERIAL AND METHODS

2.1 **Study area**

Cuiabá is considered a medium-sized city and is located in the southern region of the state of Mato Grosso (Figure 1), with an average altitude of less than 200m, latitude 15°35'46'' S and longitude 56°05'48'' W The area of the municipality is 5,077.181km², with 254.57km² corresponding to the urbanized area occupied by an estimated urban population of 623,614 (IBGE, 2022).

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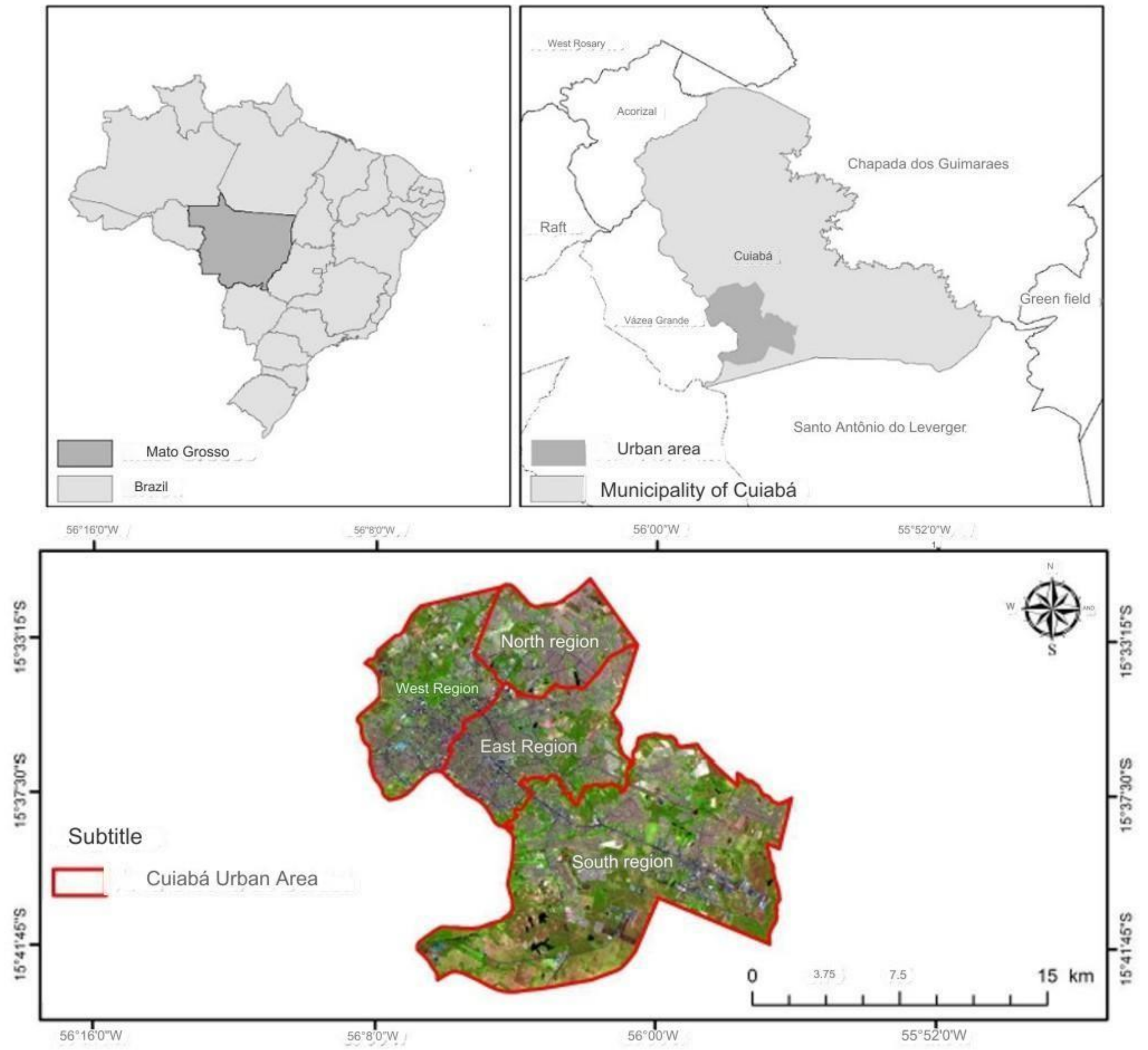
Figure 1 – Map of the location of the urban area of Cuiabá, MT, Brazil.



Source: adapted from SOUZA, 2019

The climate profile is semi-humid tropical continental type Aw, according to the Köppen classification, with two well-defined seasons, a dry season (autumn-winter) and a rainy season (spring-summer). The average annual temperature in Cuiabá ranges between 25 to 26°C, while the maximum exceeds 35°C and the minimum ranges between 18 to 21°C, relative humidity has an annual average of 70%, however during the hot period- drought reaches 12% and average total sunshine of 2,179 hours (SANTOS, 2013).

Given these characteristics, it is observed that climatic factors and elements, urban geometry, materials that cover the soil, associated with the expansion of the city, result in a city with increasingly severe climatic severity.

In this context, to collect climatic variables, the methodology of night mobile transect was adopted, with a motor vehicle, a protocol adopted when the route to be taken is very long. To measure

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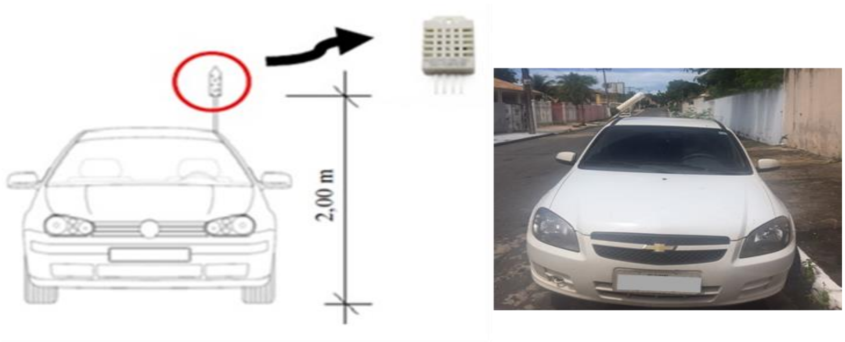
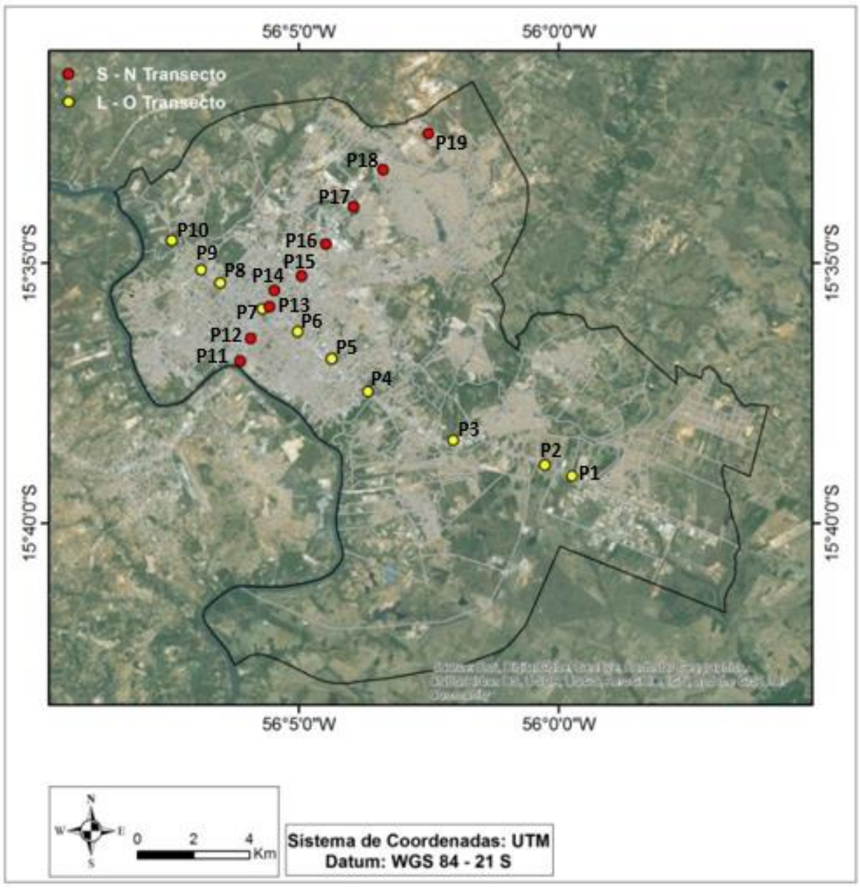
air temperature and relative humidity, a datalogger, model AM2302, was used, protected by a shelter, attached to the side of the vehicle approximately 2m from the ground (Figure 2).

Figure 2 – Photo of the Vehicle with datalogger protected by shelter



The measurements always started at 8 pm with vehicle speed varying between 30 and 40 km/h, on days with stable weather conditions, with light winds and clear skies (OKE, 2004; VALIN Jr., 2019) passing through 19 points in the city , with the East-West transect (LO) having 10 points (19.76km) and the South-North transect (SN) having 9 points (11.6km), during the summer and winter seasons of 2016 (Figure 3) .

Figure 3 – Transects



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For the accuracy of measuring points and obtaining altitudes, the Datalogger included GPS, and the coordinates were obtained in UTM (Universal Transverse Mercator), Zone 21S.

2.2 **Determination of ICU**

Oke (1987) proposes that the urban heat island is represented by the difference in air temperatures measured between urban spaces and the rural space that surrounds it. It highlights that the heat island intensity is generally observed around three to four hours after sunset.

To measure the intensity of the urban heat island, air temperature records were used from mobile transects, point by point and from the reference station considered “rural station”.

The rural station was the Meteorological Station of the National Institute of Meteorology - INMET (WMO Code: 86705), located at Marechal Rondon Airport, in Várzea Grande - MT, a city adjacent to Cuiabá-MT.

2.3 Land Cover

Katzschner (1997) proposed the integration of the climate scale and the urban planning scale to provide a link between urban climate and planning . For Prakasam (2010), land cover refers to the components that cover the Earth's surface, encompassing soil and rocks, vegetation and forests, water and snow, reflecting the biophysical state of the Earth system. While land use is related to human activities on land, such as **:** agriculture and pasture, construction, leisure and tourism, mining, deforestation, involving the modification of natural environments.

6 classes of ground cover were adopted, that is, landscape cover (undergrowth), tree cover, exposed soil, paved area, built area and bodies of water. The maps were generated using the supervised classification method, using the MAXVER technique (maximum likelihood), obtaining the percentages referring to each class of interest, with the results presented in graphic form.

2.4 **Geostatistics**

To characterize the pattern of spatial variability, geostatistical analysis will be used, with the construction of semivariograms based on semivariance calculations, that is, the spatial dependence between samples is defined by the semivariogram.

In this case **,** the parameters used are the Nugget Effect, which reveals the continuity or discontinuity of the observed phenomenon. The Range, is related to the spatial correlation of the variables, the Level, corresponds to the range in the semivariogram graph, that is, from this point onwards there is no longer spatial dependence between the variables, and the Structural Variance, which is the result of the difference between the plateau and the nugget effect (VENDRUSCULO and CARVALHO, 2004). Zanzarini et. al. (2013), show that the most used model for describing variables related to environmental sciences is the spherical model.

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To verify the best Semivariogram model, indicators are frequently used for decision making, in this sense the coefficient of determination (R^2) is adopted, varying between 0 and 1, the closer to 1 the better the model.

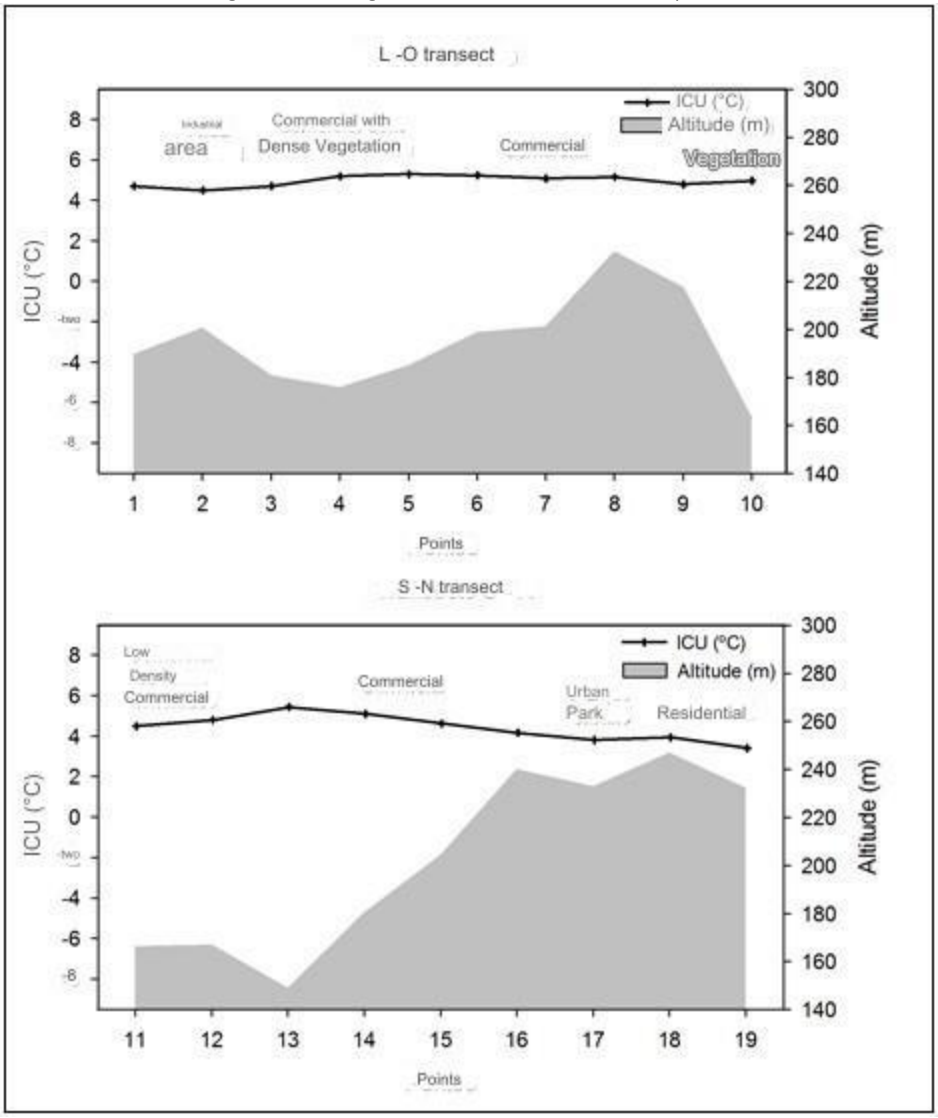
The statistical analysis used Semivariograma, carried out in the Gamma Design software and subsequently kriging the data, resulting in thermal maps of the transects of the winter and summer seasons of 2016, carried out using the Surfer v.13 software (Golden Software).

Kriging is an interpolation process that fills in the unsampled points in the reliability of the estimated values (VENDRUSCULO and CARVALHO, 2004).

3 RESULTS/DISCUSSIONS

According to Figure 4, Cuiabá expresses an average urban heat island of 4.70°C in summer, with a thermal variation of 1°C. Furthermore, the ICU intensities are observed at points 4, 5, 6, 7.8, 13 and 14, varying between 5.00 and 5.40°C.

Figure 4 – Average ICU Summer and Altitude of points



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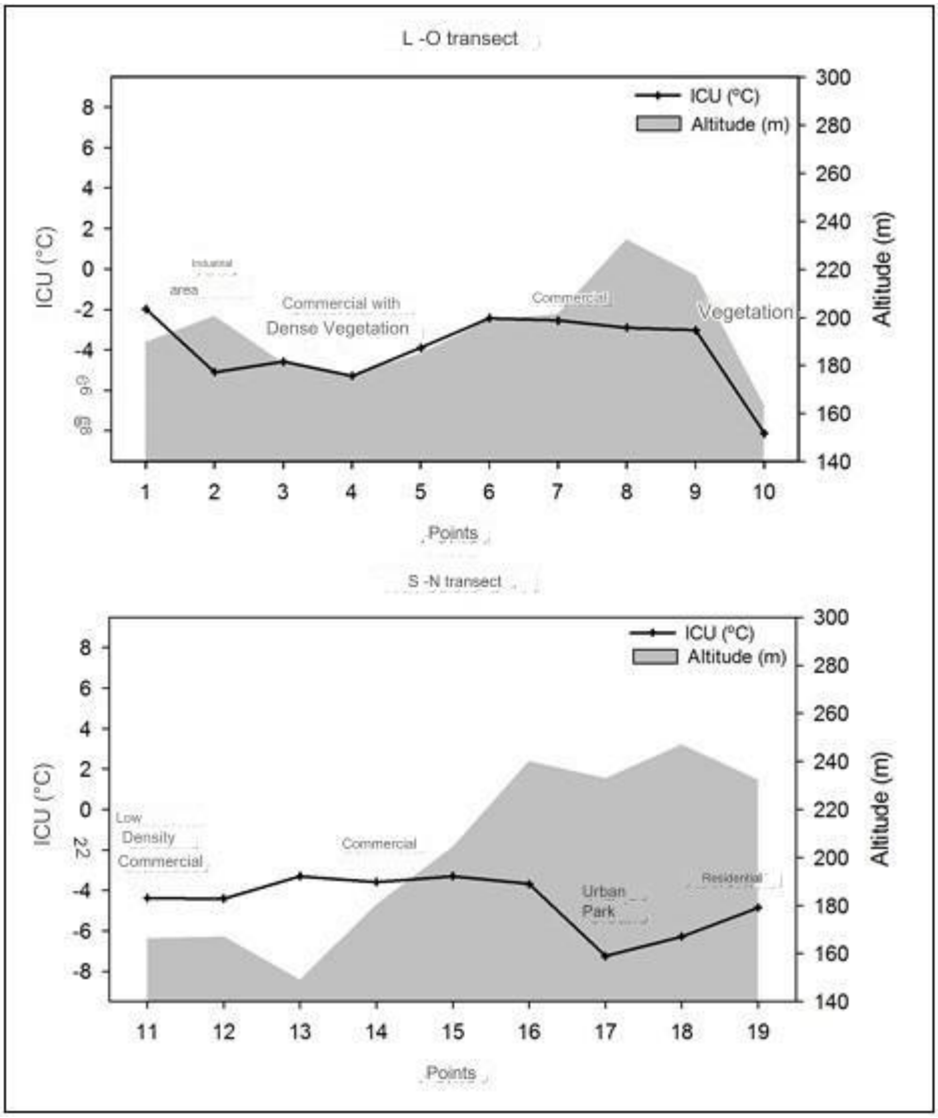
Analyzing the transects, LO and SN, it is observed that the average difference in ICU expressed between them is 0.5°C, that is, 4.90 and 4.40°C, respectively. The lowest ICU intensities are observed in the SN transect, at points 17, 18, and 19, being point 17.

In winter, all points showed negative ICU values, thus characterizing the presence of an island of coolness, with an average of -4.26°C. However, the thermal variation observed at this station is 6°C, at points 1 and 10 (Figure 5).

Figure 5 – Average Winter ICU and Point Altitude



When considering the two transects, LO and SN, it is observed that the average difference in ICU expressed between them is 0.6°C, that is, 4.00 and 4.60°C. However, in both transects at this station, there is greater variation between points.

Oke (1981) recommends the summer season to investigate the urban heat island. However, in Cuiabá, it was in the winter season that the best relationship between ICU and land use and

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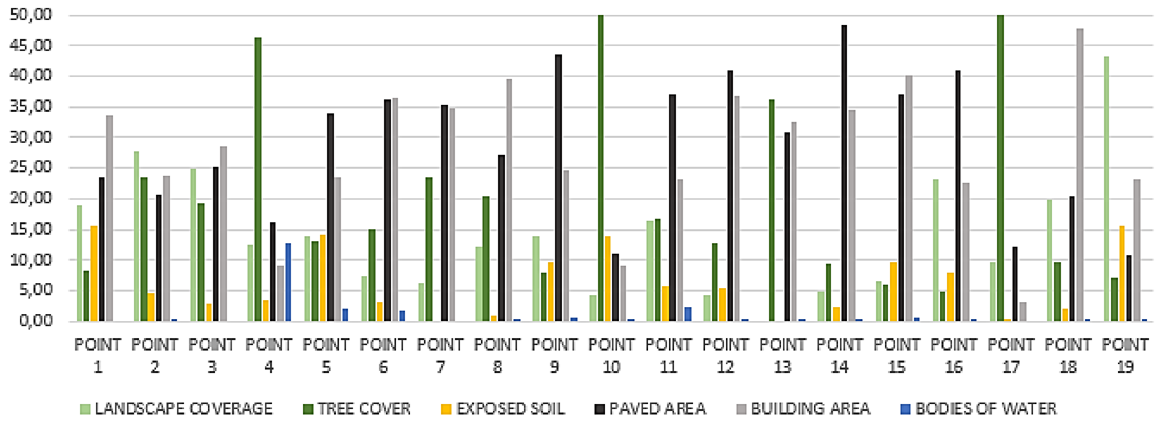
occupation characteristics was observed, due to the hot-dry period, that is, the low precipitation characteristic of the period (SANTOS, 2013) .

Regarding the relationship between altitude and ICU, the average altitude between the transects is approximately 198m. In this way, it is observed that in 47% of the points the highest ICUs are at the lowest altitude points, that is, below 198m, in greater concentration in the LO direction.

As for soil cover, the lowest ICU intensities are observed in the SN transect, at points 17, 18, and 19, with point 17 located in a vegetated area - urban park, and point 19 in a residential area with a marked presence of vegetation. In turn, the highest intensities were recorded at points 4, 5, 6, 7, 8, 13 and 14, in areas where the soil cover is predominantly impermeable with commercial and service activities, as shown in figure 6.

Figure 6 – Land cover in 2016



It is known that cities can significantly alter the natural conditions of surfaces and atmospheric properties, resulting in different warming patterns in urban areas (CARDOSO et al. 2017).

As well as the strong relationship between soil cover and air temperature, especially with regard to urban density and vegetation. Pereira et al. (2002) state that the space-time variation in air temperature is conditioned by the energy balance at the surface, one of the most important effects of solar radiation.

The semivariographic model used for kriging the urban heat island was the spherical model with normal distribution. In summer (Figure 7), the data has a normal distribution with symmetric kurtosis to the left, presenting R^2=0.76, nugget effect equal to 0.0010, level equal to 0.4540. The spatial dependence was obtained through the range (Ao), at this station it was 8400m, that is, moderate dependence.

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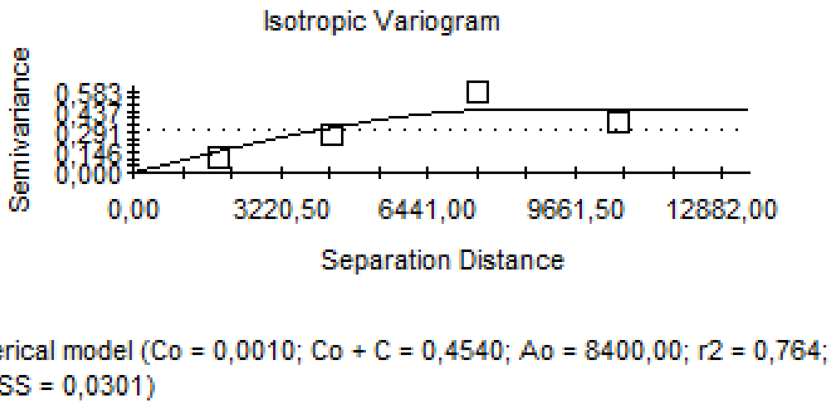
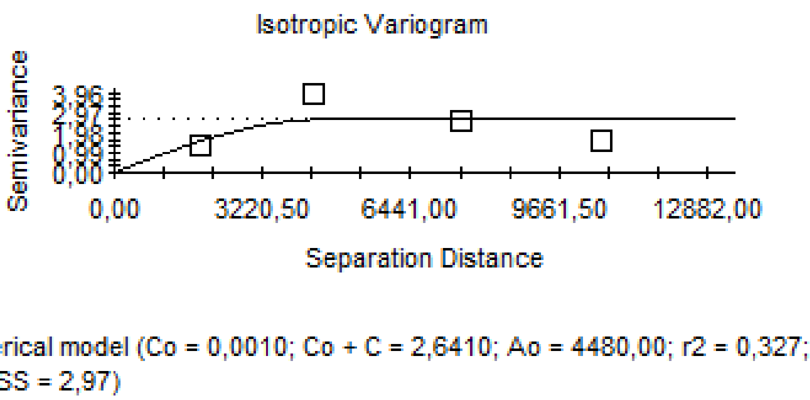
Figure 7 – Semivariogram used for kriging of the Summer ICU



In winter (Figure 8), the data have a normal distribution with right-symmetric kurtosis with R^2 of 0.327, the nugget effect was 0.0010 and the threshold was 2.6410. Regarding the range (Ao), at this station it was 4480 m, that is, strong dependence.

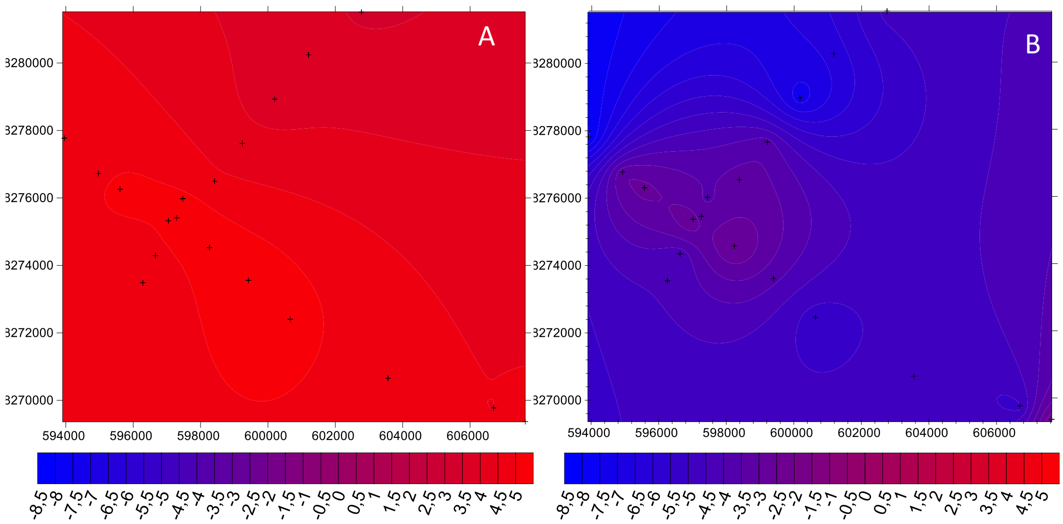
Figure 8 – Semivariogram used for kriging the Winter ICU



In this study, these models were used to krig the ICUs, the resulting maps can be seen in Figure 9. A pattern is observed in the analyzed points, with the central areas of the city being warmer whether in the summer or winter season.

By analyzing the behavior of the urban heat island in the summer and winter seasons, it is concluded that summer is more conducive to observing the intensity of the urban heat island. In the study carried out, an intensity of 4.70°C was recorded, being associated with a decrease in permeable coverage and an increase in impermeable coverage.

Figure 9 – Kriging Urban heat island (°C), (A) Summer (B) Winter



While in winter the "island of freshness" phenomenon was found, where the city is colder than its rural area, reaching an intensity of -4.26°C. Showing that areas under the influence of large masses of vegetation presented specific characteristics with different microclimates to other areas of the city, due to the loss of energy to the environment, used in the processes of photosynthesis, evapotranspiration and thermal exchange by convection.

Corroborating the studies carried out by Franco et. al. (2012) and Paula et. al. (2016), about the strong influence that soil waterproofing has on the thermal behavior of an environment, as heat absorbed by the asphalt and building surface is released.

4 FINAL CONSIDERATIONS

By analyzing the behavior of the urban heat island in the summer and winter seasons, it is concluded that summer is more likely to observe the highest heat island peaks, resulting in an increase of 4.70°C. Demonstrating that changes resulting from urbanization with the use of impermeable materials contribute considerably to the increase in air temperature and decrease in relative air humidity on a microclimatic scale.

While in winter the "island of freshness" phenomenon was found, where the city is colder than its surroundings, around -4.26°C. Highlighting that areas under the influence of large masses of vegetation presented specific characteristics with different microclimates to other areas of the city.

The application of geostatistics, especially the use of semivariogram, proved to be satisfactory in data analysis. The spherical model presented a normal distribution sometimes to the left and sometimes to the right, a nugget effect of 0.0010 in both seasons, the threshold was 0.45 in summer and 2.64 in winter, and a range of 8400 and 4480, respectively. Showing moderate to strong correlation and spatial dependence, that is, the ICU in winter is strongly influenced by soil cover.

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