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Papers

Geographic analysis of the distribution of surface temperature, vegetation cover and its relationship with socioeconomic indicators – Cuiabá/MT

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Temperature

Abstract

In Brazil and around the world, the problems resulting from urban planning, changes in land cover and the increase in urban infrastructure influence temperature change. The aim of this research is to understand the difference in temperature over the last 36 years (1985-2021) in the city of Cuiabá/MT, and its relationship with vegetation and socioeconomic and racial-ethnic factors. Annual images (36 images) from the Landsat 5 and 8 satellites between 1985 and 2021 were used, and Google Earth Engine was used to obtain this data for the urban area of the city of Cuiabá. Mapping of the spatial distribution of surface temperature, vegetation and changes in land use and cover was carried out using data from the MapBiomas project and socio-economic data from the Instituto Brasileiro de Geografia e Estatística (IBGE, Brazilian Institute of Geography and Statistics in English) 2010 census. The results indicated that over the last 36 years Cuiabá's surface temperature has increased by an average of 13°C, as part of the result of the growth of urban infrastructure and loss of vegetation cover, specifically in the peripheral areas. There is an inequality between the high-income population living in neighborhoods with milder temperatures and the low-income population living in neighborhoods with higher temperatures. In the temperature and skin color data, the white population generally lives in neighborhoods with milder temperatures, unlike the black population, which mostly suffers from high temperatures.

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INTRODUCTION

In Brazil and other tropical countries, the production model for urban spaces involves the removal of vegetation for occupation, urban concentration, construction with materials that have low thermal capacity, and an excess of fossil fuel emitting vehicles (Silva, 2021; Freitas; Cunha, 2013). As a result, the urban climate is intensified, with high temperatures and urban heat islands, reducing the relative humidity of the air. The municipality of Cuiabá is no different. Known for having a hot climate during the dry season (August to October), its high temperature is particularly aggravated by natural and social factors, causing great thermal discomfort (Teobaldo Neto, 2019).

Urban open spaces in cities such as Presidente Prudente and Ribeirão Preto - SP, are unevenly distributed, with variations in infrastructure and the presence of vegetation between central and peripheral neighborhoods (Gomes; Soares, 2003). Not everyone is affected by excess heat and understanding who is affected is important. Thus, as the urbanization process in Brazilian cities is related to the capitalist logic of urban space production, which generates segregated and fragmented spaces and does not consider environmental and natural conditions, it has become common to identify sensitive impacts on different social groups living in the city (Sant'anna Neto, 2011). A study by Benz and Burney (2021) in the USA showed the temperature inequality in neighborhoods, comparing places where the majority of the population is low-income or black, considering that in these neighborhoods the temperature is higher than in white and high-income neighborhoods. Several studies in Brazil and around the world focus on this subject (Cutter; Finch, 2008; Freitas *et al*., 2013; Costa *et al*., 2015; Pascolino; Junior, 2021) where they carry out research using satellite images and census data. Dias *et al.* (2023) analyzed the spatial relationship between temperature and socioeconomic inequality in the city of São Paulo - SP, obtaining NDVI and temperature values between 2009 and 2010, with soil sealing data, and observed that the highest temperatures were located in the lowest income areas, indicating socio-spatial, economic and environmental segregation.

The use of remote sensing for measurements at different scales and analysis of urban environments using orbital platforms is increasingly being applied to different studies, such as spatial analysis and land use changes. Rhee *et al.* (2014) related land cover patterns and surface temperature using simple linear regression and the Random Forest *classifier* in Denver, Colorado (United States). Thus, the results showed that some soil cover patterns affect surface temperature, such as tree cover, which is the most important special feature affecting surface temperature. In the article by Guha *et al.* (2018), using Landsat 8 OLI and TIRS data in the cities of Florence and Naples, Italy, the relationship between surface temperature, NDVI and the accumulated normalized difference index (NDBI) was verified (NDBI) and identified that exposed soil and built-up areas are mainly responsible for the 3.15°C and 3.31°C increase in surface temperature. And when vegetation and bodies of water are present, the surface temperature level drops.

Thus, many studies relate temperature to the lack of vegetation and even to spatial segregation, and so urban monitoring takes place in order to detect successful land use transformations and analyze the consequences. In order to identify changes in land use, it is necessary to identify the type, quantity and location of the changes, while in order to analyze the impacts of land use, it is necessary to assess the effects of the changes on the environment.

At 304 years old, Cuiabá is an old city when compared to other cities in the state of Mato Grosso, so we can see problems resulting from the city's urban planning, which used to be considered a "green" city. Urban land cover has changed over the years and areas with urban infrastructure have increased, leading to a decrease in green areas. Teobaldo Neto (2019) investigated the extent of the risk/hazard posed by the urban climate during the dry season (August and October) in Cuiabá. With urban sprawl creating structured spaces in elite neighborhoods and spaces occupied by the low-income population, inequality has worsened along with rising air temperatures in the urban area.

Exposure to dangers or even environmental disasters and vulnerability is a result of the unequal history of urbanization and the production of spaces, which concludes the socio-spatial difference and its selective occupation. Inequality in the urban space is a product of the way in which each territory has been built, so the urban climate risks in each territory differ. In addition to social inequality, vulnerability shows the association of historical and socioeconomic factors (Rampazzo, 2019). Risk only occurs when vulnerability is explained, vulnerability is not risk, but risk only exists because of vulnerability and can only be reduced by changing the structure and organization of vulnerability in space (Nascimento junior, 2018). According to Ugeda Júnior (2015), the risk is created socially, and the population is exposed to it in different ways, resulting in vulnerability.

In the analysis of the urban heat island, the low latitudes and altitude were affirmative reasons for the hot climate. During this period, thermal discomfort in the city of Cuiabá is intensified not only due to scarce vegetation cover, fires and fossil fuel emissions in traffic, but also by the influence of continentality and low altitudes (Maitelli, 1994).

Therefore, the general objective of this study is to carry out a geographic analysis in the city of Cuiabá correlating surface temperature data and vegetation cover data over the last 36 years. The aim is to analyze whether there is a relationship between temperature and vegetation data with socio-spatial segregation within the urban area of the city of Cuiabá.

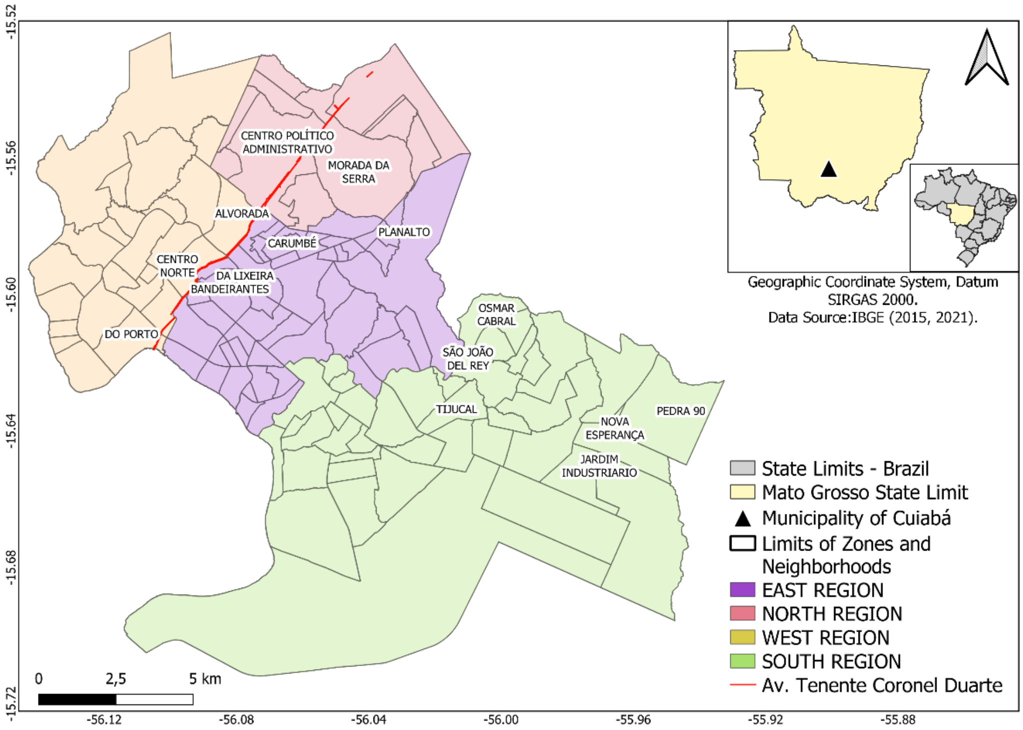
MATERIALS AND METHODS

Study area

The municipality of Cuiabá is located in the Center-West region of Brazil, in the mesoregion Centro-sul Mato-Grossense, in the south of the state of Mato Grosso, Microregion Cuiabá. Its territorial area is 4,327.448 km², with a population of 650,912 according to the latest IBGE census (2022). The predominant climate in the municipal region is classified as tropical hot and sub-humid, with a total annual rainfall of 1350 mm, with greater intensity in the months of December, January and February, with an average annual temperature of 26.46ºC, according to the latest climatological normal from 1991 to 2020 (INPE, 2023).

Its main economic activities are industry, commerce, livestock farming, fishing, subsistence farming and fruit and vegetable growing (Ferreira, 2001). The territorial division of the city's urban area consists of 115 neighborhoods (Figure 01) and the subdivision of the administrative region is divided into 4 zones: North Region with 10 neighborhoods, South Region with 34 neighborhoods and 1 industrial district, East Region with 49 neighborhoods, and the West Region with 24 neighborhoods (Prefeitura Municipal de Cuiabá, 2010).

Figure 1 - Map showing the urban area of Cuiabá and its boundaries (IBGE, 2015, 2021).



Source: The authors (2024).

Surface temperature and vegetation data

To obtain the Surface Temperature and NDVI data, the Landsat 5 and Landsat 8 images were obtained from the Google Earth Engine database (Gorelick *et al*., 2017), which contains an atmospherically corrected surface reflectance data set, in addition to the geometric correction, the catalog product used is the ('LANDSAT/LT05/C02/T1_L2') and ('LANDSAT/LC08/C02/T1_L2'). The spatial resolution of the images is 30 meters.

The time series of images was from 1985 to 2021, where cloud-free images were selected through filtering processes and, subsequently, the annual average values for the drought months (August to October) of temperature (Landsat 5 Band 6 and Landsat 8 Band 10) were extracted. The annual average values for the months of drought (August to October) were extracted from the Temperature values (Band 6 of Landsat 5 and Band 10 of Landsat 8) and the annual average values for the months of drought (August to October) from NDVI for the entire municipality, totaling a time series of 36 images. The script built in the GEE can be accessed at GOOGLE (2024).

It is important to note that only the months of the dry season were chosen to acquire the images, as they have low cloud cover, unlike the rainy season, where the images are always covered with high percentages of clouds. The NDVI is a vegetation index proposed by Rouse *et al*. (1973), obtained from the ratio between the subtraction and sum of the reflectances of the bands in the near-infrared (NIR) and red (Red) regions of the electromagnetic spectrum. Equation (01).

$$\text{NDVI} = (\text{NIR} - \text{RED}) / (\text{NIR} + \text{RED}) \quad (01)$$

In order to analyze whether there is a relationship between socioeconomic data from the IBGE and temperature and NDVI data for different areas of Cuiabá, data from the average dry season was used, only from 2009 with Landsat 5 images. It is important to note that the selection of the year 2009 to examine the correlation between IBGE data and temperature and vegetation data is based on its proximity to the latest census available at the time of this research (IBGE, 2010). In addition, the dry period was chosen because of the absence of clouds in the satellite images.

Land use and land cover data

To identify changes and transformations in land use and cover and relate them to temperature and NDVI data, we used data from the MapBiomas Project, Collection 7.1. The data was acquired at level 1 with 5 classes (Forest, Non-forest natural formation, Agriculture, Non-vegetated area and Body of water), using two land use and land cover maps from 1985 and 2021.

The quantification and analysis of land use and land cover transformation processes over the last 36 years were carried out based on a cross-tabulation between the 1985 and 2021 land use and land cover maps. Based on this procedure, it was possible to quantify and map the land use and land cover classes that showed gains or losses in the area and to identify the most significant classes for changes in the landscape of the study area, especially the forest classes in non-vegetated areas (urban areas).

Socio-economic data

According to Villaça (2001), spatial segregation can be characterized as a process according to which different social classes or strata tend to concentrate more and more in different regions of the metropolis. In other words, a separation in space of the population by income class, race, ethnicity, socio-professional occupation, among other variables. According to Hughes (2004) and Negri (2008), there are various types of spatial segregation, such as race, ethnicity, class, socio-economic and others. In the case of Brazil, most research (Carvalho, 2020; Gomes-ribeiro; Queiroz-ribeiro, 2021) shows that one of the main types of spatial segregation is socioeconomic (income and race), whereby social classes are distributed unevenly in the urban space of large and medium-sized cities.

Having considered the principles of spatial segregation, it was decided to select two socio-economic variables from the IBGE (income and race) to establish correlations with surface temperature and vegetation data. To check whether there is a relationship between spatial segregation and the spatial distribution of surface temperature in the urban area of Cuiabá, IBGE data was used for census sectors in 2010, the year of the last census carried out in Brazil, which represents the smallest intra-urban territorial unit containing socio-economic data.

Only census tracts classified as urban were selected, totaling 799 tracts. Based on the results per universe per census sector, the "Average nominal monthly income of people responsible for permanent private households (with and without income)" was chosen as the economic variable in the basic table, variable v005.

Subsequently, the aforementioned census variable was classified into social classes (Table 1) according to Costa's classification (2019). It is worth noting that according to the national average, in 2010 more than 50% of the Brazilian population fell into class C, while approximately 11% were in classes A and B, and less than 40% were in classes D and E. Class C was therefore divided into two brackets: C1 and C2, in line with the study by Dias *et al.* (2023), in order to minimize the discrepancy between the number of individuals in these income brackets.

Table 1 - Relationship between social classes and income per minimum wage.

Class	Minimum Wages
A e B	> 10
C1	6 a 10
C2	4 a 6
D	2 a 4
E	< 2

Source: Costa (2019).

For the social variable, color or race was chosen from the table " Planilha pessoas 03_MT ", variables Resident People and color or race - white (v002) and variables Resident People and color or race - black (v003), divided by the total population (v001) to calculate the percentage for each census tract.

Statistical analyses

The unit of analysis used was the boundaries of the 2010 IBGE census sectors. The study area has 799 census tracts. To check whether there is a relationship between spatial segregation and the spatial distribution of surface temperature in the urban area of Cuiabá, the average surface temperature values were extracted for each census sector and cross-referenced with socio-economic data from the IBGE.

For this stage, Pearson's correlation coefficient was calculated between the IBGE data and the average temperature data per census sector to assess whether there is a relationship between the variables. The relationship between surface temperature and socioeconomic data (Income and Population Color) was also tested, when the Shapiro-Wilk normality test was initially carried out to check whether the data sample followed a normal (Gaussian) distribution. Subsequently, the Kruskal-Wallis (KW) and Games-Howell (GH) non-parametric tests were used to check for significant differences between the independent groups (classes). Equation (02).

$$H = 12/(N(N+1))\sum_{i=1}^{k}(R_i^2/n_i) - 3(N+1) \quad (02)$$

Where:

- H is the KW test statistic.
- N is the total number of observations.
- k is the number of independent groups.
- R_i is the sum of the ranks of the values in group i.
- n_i is the number of observations in group i.

If the KW test indicated statistical significance, the Games-Howell (GH) test was used to specifically test which groups had significant differences. The test statistic (Equation 03) is based on the standardized mean difference between groups and is given by:

$$t_{ij} = (\bar{X}i - \bar{X}j)/\sqrt{(s_i^2/n_i) + (s_j^2/n_j)} \quad (03)$$

Where:

- t_{ij} is the GH test statistic between groups i and j.
- $\bar{X}i - \bar{X}j$ are the averages of groups i and j, respectively.
- s_i^2 and s_j^2 are the variances of groups i and j, respectively.
- n_i and n_j are the sizes of groups i and j, respectively.

The free software QGIS, version 3.16, was used for spatial analysis and map making.

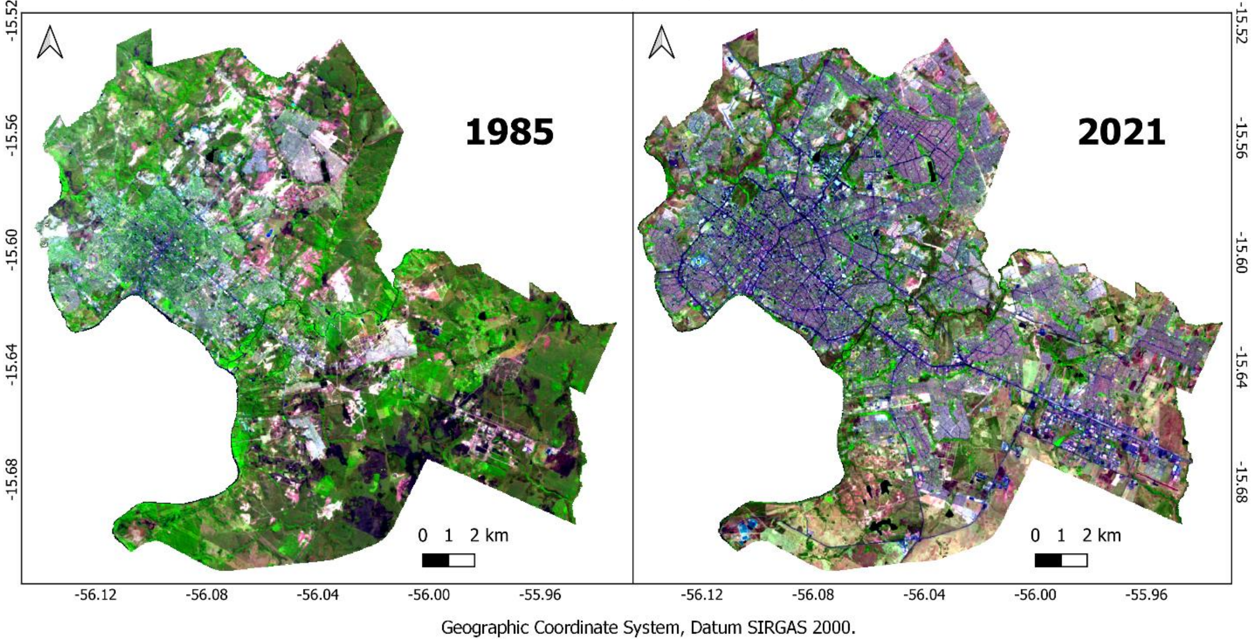
Boxplot graphs and statistical analyses were carried out using the *Statsmodels software* in the *Python environment*. Statistical analysis and regression graphs were carried out using *Microsoft Office Excel* 2013.

RESULTS AND DISCUSSION

Analysis of the transformation of land use and cover and the dynamics of temperature and vegetation cover

The false-color satellite images of Cuiabá's urban area from bands 5, 4 and 3 (Landsat 5) and 6, 5 and 4 (Landsat 8), captured in 1985 and 2021, are shown in Figure 2. In 30 years, the urban sprawl has clearly increased and its expansion has mainly taken place over areas of vegetation (Cerrado) and pasture, with more intensity in the north and east of the city.

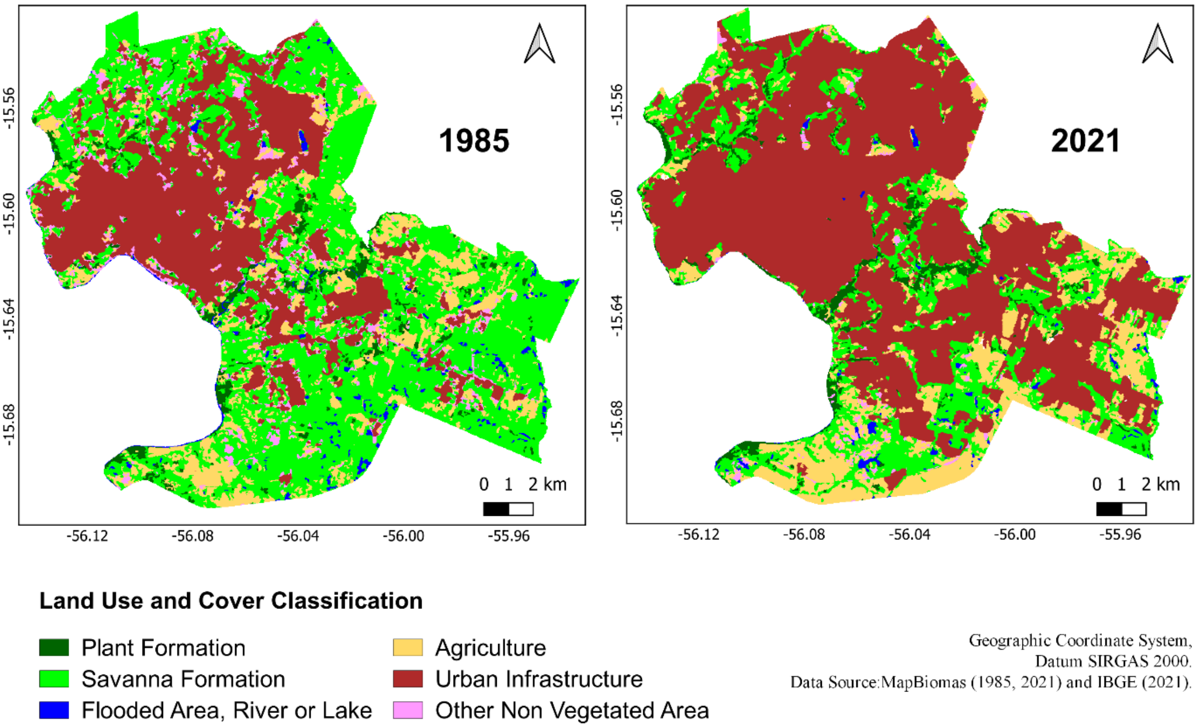
Figure 2 - Satellite image (1985) Landsat 5 in composition 3(B), 5(R) and 4(G) and (2021) Landsat 8 in composition 4(B), 6(R) and 5(G).



Source: IBGE (2021) and NASA (2023). Elaborated by the authors (2024).

The land use and cover map from the MapBiomas project for the city of Cuiabá (Figure 3) has the following classes: forest formation, grassland formation, mosaic of agriculture and pasture, crop mosaic, other non-vegetated areas, pasture, bodies of water, savannah formation (cerrado), wetlands, mining and urban area. The area occupied by urban infrastructure (burgundy color) from 1985 to 2021 increased mainly in the northern regions and between the East-West region, in the so-called central core of the city. We also see an increase in areas with farming (yellow color) in the southern region. The areas that have seen the most urban growth are in the north and east of the municipality, which used to be occupied by wetlands, rivers or lakes, agriculture and livestock, forestry and, above all, savannahs.

Figure 3 - Land use and land cover classification map for 1985 and 2021. (MapBiomas 1985, 2021; IBGE, 2021)



Source: The authors (2024).

The total area/ha of each classification, with the percentage of loss and gain, for the years 1985 and 2021 is shown below (Table 2).

Table 2 - Land use classification with total area (%) of loss and gain.

Land Use Classification	1985 (Area/ha)	2021 (Area/ha)	Loss/Gain (%)
Urban infrastructure	7,558,76	15,157.60	100.53%
Agriculture	3,360,96	3,907.15	16.25%
Forest formation	792.028	868.145	9.61%
Flooded area, river or lake	402.536	212.715	-47.16%
Savanna Formation	11,846.36	4,906.19	-58.58%
Non-vegetated areas	1,421.13	330.031	-76.78%

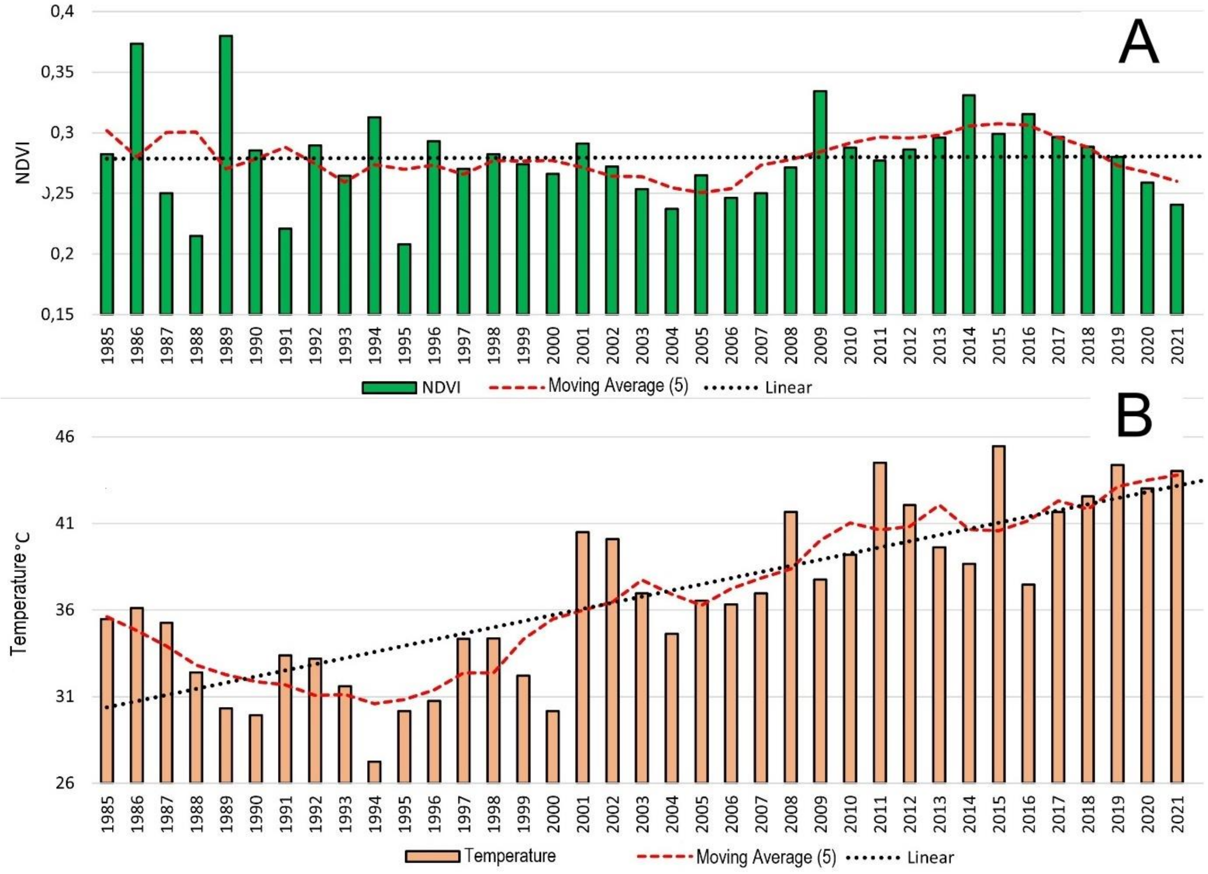
Source: The authors (2024).

Thus, the results showed that the percentage of urban area was the class that increased the most between 1985 and 2021. One of the reasons for the increase was greater social interference with the growth of the urban population, which in 1985 was 283,075 people (IBGE, 1985) and in 2021 rose to 650,912 people (IBGE, 2022).

According to data extracted from the Mapbiomas Project between 1985 and 2021, there was a conversion mainly of the Savannah Formation areas (cerrado) to urban areas, which may have contributed to the increase in temperature in some neighborhoods, since As Peng and Li (2009) point out, "the changes caused by man affect the energy balance, generating heat islands and air quality, impacted by the emission of atmospheric effluents".

By processing the Landsat 5 and 8 time series, we obtained the average surface temperature and NDVI values for the drought months in Cuiabá, in areas where urban expansion occurred over vegetated areas from 1985 to 2021 (Figure 4). The results were obtained from the average NDVI and temperature data processed using Landsat 5 and 8, and the average values of the transition areas were calculated. The average values of the transition areas to urban infrastructure were calculated, so that we could analyze and identify the changes and differences, as well as whether there was an increase in temperature over the years, and whether there was a decrease in NDVI values between the years 1985 and 2021.

Figure 4 - Graphs of the averages over time of NDVI and Surface Temperature for the urban area of Cuiabá



Source: The authors (2024).

Looking at the results obtained with the average NDVI values located in the transition areas in the urban area of Cuiabá (Figure 4), we can see that at the beginning of the series, the amplitudes between the years 1985 and 1994 are greater than in the following years, due to the different land uses and coverage over time. What used to be savannah and grassland, with a strong influence from the dry and rainy seasons, has been converted to urban areas, which don't suffer as much influence throughout the seasons, keeping NDVI values stable over time. The fluctuations in NDVI values in some years are caused by noise in the time series, such as clouds and years when the dry period was more intense. It is important to note that there has been a downward trend in NDVI values in recent years, which may indicate a growing urbanization process in the city of Cuiabá.

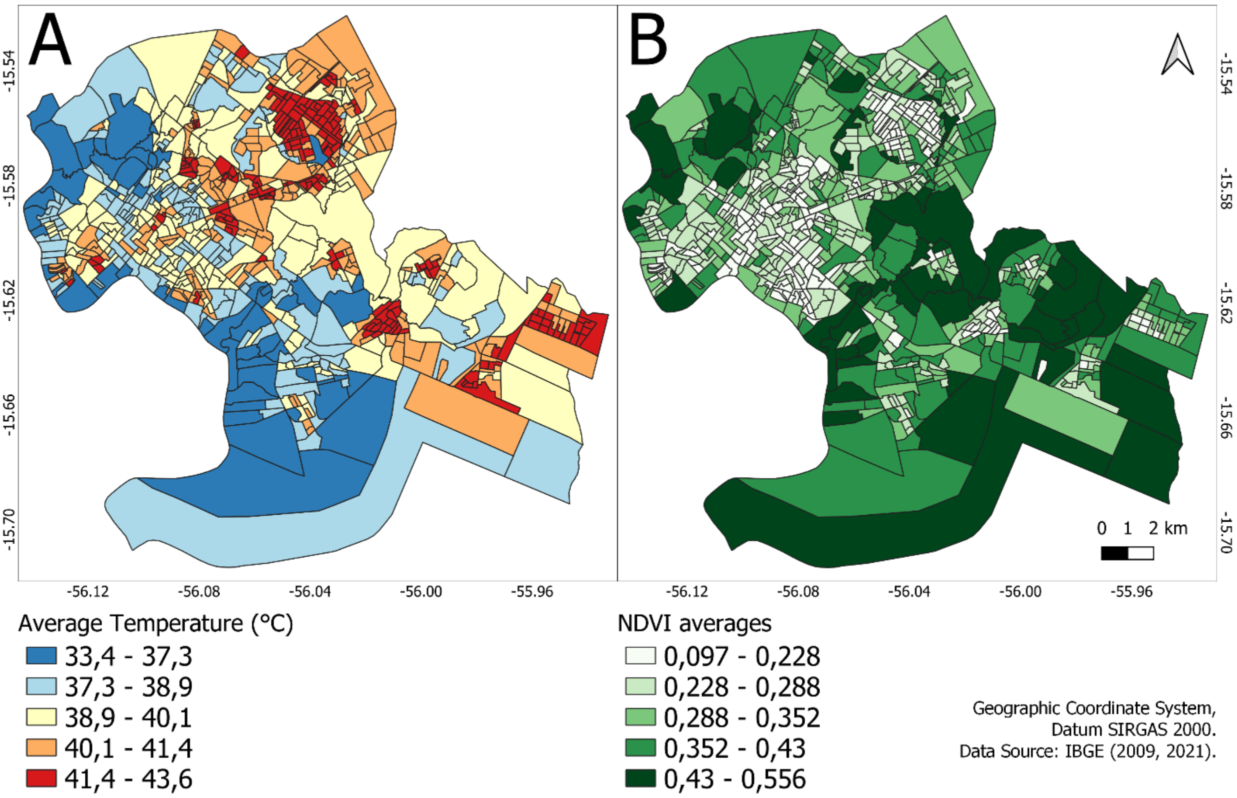
One of the hypotheses for the little change in NDVI values over the years may be related to the fact that the savannah vegetation (cerrado) has been converted into an urban area, and normally cerrado vegetation in the dry season (the period of the images) is dry, in other words, the NDVI values are extremely low, very similar spectrally to the average values of an urban area.

The surface temperature averages for the transition areas behave in two ways: there is a drop between 1985 and 1994, and an increase between 1995 and 2021. When analyzing the data at the beginning of the 1990s, the average surface temperature was around 27°C to 29°C. By the end of the time series, the average temperature had risen to 43.8°C. By the end of the time series, the average temperature had risen to 43.8°C, an average increase of around 13°C, which is quite considerable over this short period of study. This increase in surface temperature between 1985 and 2021, in all regions of Cuiabá, was due to the expansion of the city, with the growth of the population and urban infrastructure, where before the soil was mostly occupied by vegetation and savannahs. It is important to note that, over the last few decades, there have been significant influences on global temperatures as a result of climate change. There has been a continuous increase in the average global temperature, especially since the 1980s. Notably, the year 2023 recorded the largest positive anomaly since historical records began (1850), with an increase of 1.79°C (NOAA, 2024).

Spatial segregation and spatial distribution of surface temperature in the city of Cuiabá

For a clearer analysis of the temperature distribution in the city, Figure 5 shows the average temperature map and the map with the average NDVI values, both by census tract for 2009, the year of the census, between the months of the region's drought (August to October).

Figure 5 - Maps of surface temperature averages from August to October 2009 by census tract (A). Average NDVI values by census tract for 2009 (B) (IBGE, 2009, 2021)



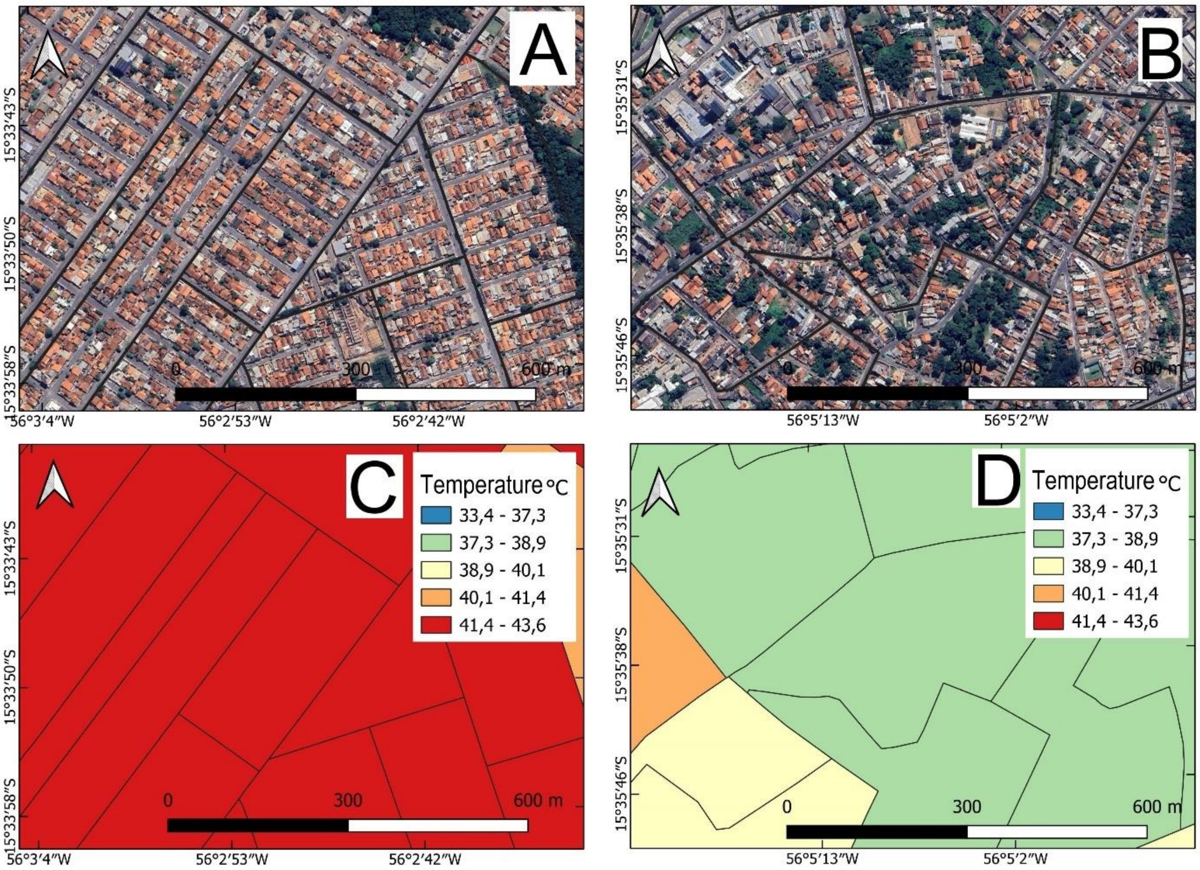
Source: The authors (2024).

As a result, we analyzed that the highest average temperature is located on the outskirts of the city, while the areas close to the Cuiabá River had the lowest average temperature in the city. The Centro Político Administrativo (CPA), Morada da Serra and Pedra 90 neighborhoods stand out with high average temperature values per census tract, red shades on the map (figure 5), all neighborhoods with little vegetation cover. On the other hand, some census tracts located in the central region of the city, shades of blue on the map, do not have extreme temperatures with average values between 37.3°C and 40.1°C, mainly because they have squares and tree-lined streets, thus mitigating the high temperature.

In relation to the NDVI map, in some regions, such as the city center, the average NDVI values are very low, due to the large urban concentration, it is also due to intense urbanization and little vegetation cover, which can lead to extreme temperature values, especially in the hottest months of the year (August and September). On the other hand, the southern region of the city has the highest NDVI values, which is explained by the low level of urbanization in these areas and the high concentrations of vegetation cover, since these regions with the largest areas have not undergone the transition to urban areas like the more central region, but rather the transition to farming and cattle raising, as well as the fact that they are industrial areas of the city. The high urban coverage in the central area between the East and West regions is explained by the fact that it was the initial nucleus, where the city began to expand and then headed in a northeasterly direction, along Avenida Tenente Coronel Duarte, which explains the urban concentration in the North region. (Figueredo *et al.*, 2019)

There is also a difference in urban coverage between the central neighborhoods (da Lixeira, Centro Norte and Bandeirante) and the outlying neighborhoods (CPA and Morada da Serra), where houses are built closer together (Figure 6).

Figure 6 - (A) High-resolution image of the CPA and Morada da Serra regions. (B) High-resolution image of the Lixeira neighborhood. (C) Surface temperature of the CPA and Morada da Serra regions. (D) Surface temperature of the Lixeira neighborhood.

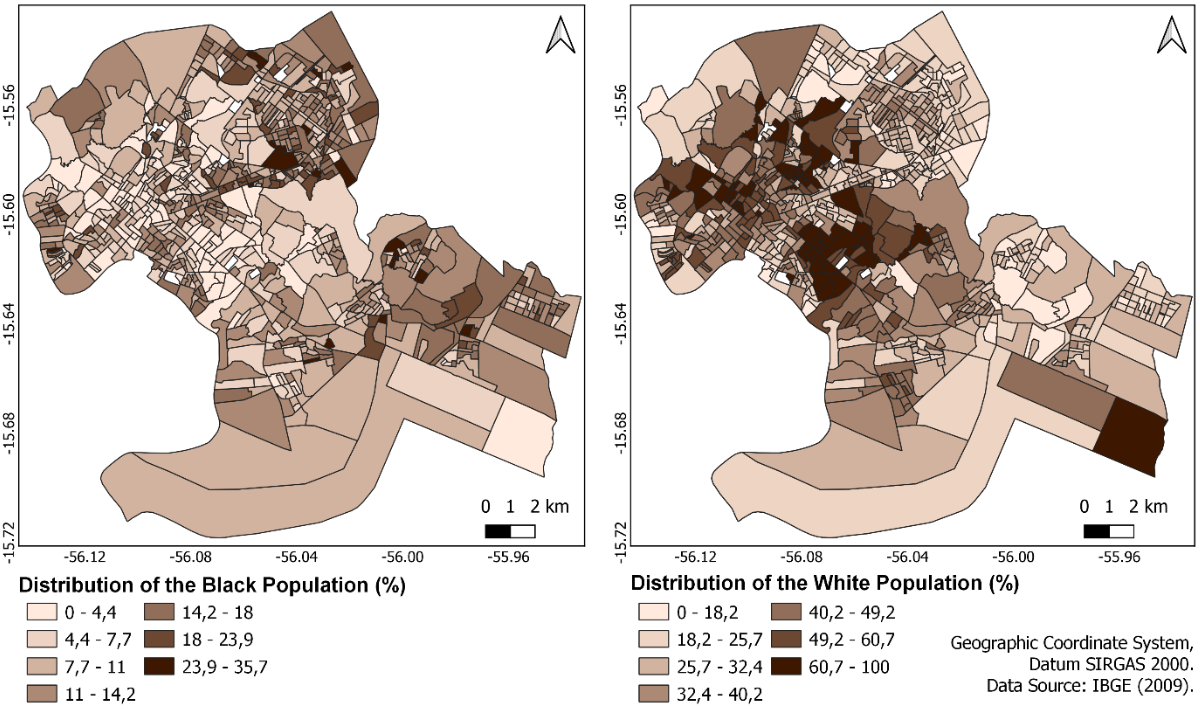


Source: IBGE (2009) and Google (2024). Elaborated by the authors (2023).

To compare the surface temperature and NDVI data, the CPA and Morada da Serra regions (Letters A and C in Figure 6) have temperature values of 43.33°C and average NDVI of 0.19, i.e. high temperatures and low vegetation cover. While in the Lixeira neighborhood (Letters B and D in Figure 6), which is known for being more wooded, the average surface temperature was 38.39°C and the average NDVI was 0.29, which is around 5°C less than the CPA region. With regard to economic aspects, the warmer neighborhoods, such as CPA, have an average income of R$2.006.26 or 4.31 minimum wages for the time, while in the Lixeira neighborhood, the average income is higher, at R$ 2,718.80 or 5.84 minimum wages for the time.

In order to understand whether there is a relationship between temperature and racial/ethnic distribution, we plotted the data on the distribution by census sector (2009) of the black and white populations in the urban area of Cuiabá (Figure 7). We can see that the majority of the black population is distributed on the outskirts of the city, in the north and south, while the white population is mostly distributed in the central area of the city.

Figure 7 - Map of the distribution of the black and white population in census tracts (IBGE, 2009)

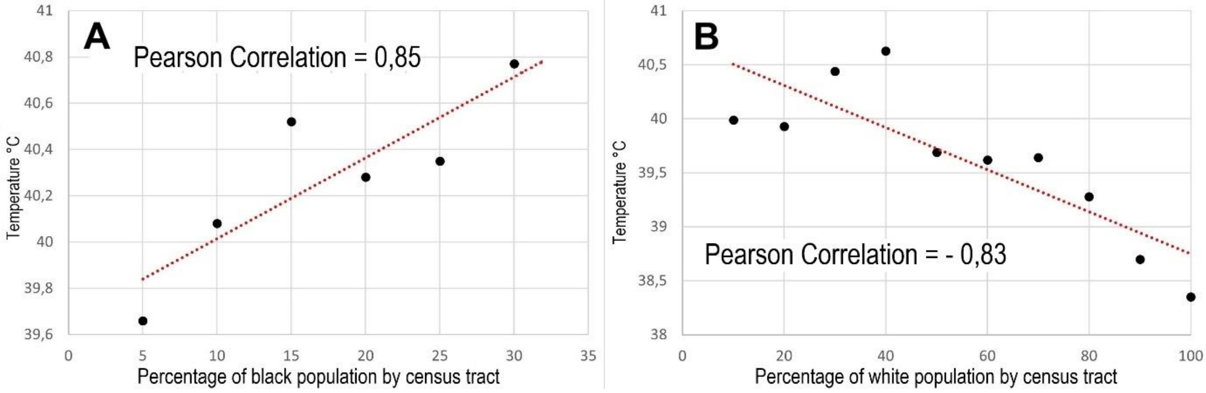


Source: The authors (2024).

The scatter plot between temperature and percentage of black and white population by census tract (Figure 8), generated by applying the Pearson correlation coefficient, shows that the relationship between temperature and percentage of white population is inversely proportional (B). For the black population (A), the data shows a correlation value of 0.85, indicating a strong relationship between surface temperature and population color, with the positive sign indicating that the relationship between the variables is direct, i.e. by increasing the percentage of black population within the census tract, the temperature will also gradually increase. For the white population, the opposite is true: the correlation value was -0.83, indicating a strong relationship, but with a negative sign indicating that the relationship between the variables is inverse. The percentage of the white population in the census tract increases as the temperature drops.

The results of this research corroborate the idea that there is a fragmentation between social and racial classes and the spatial distribution of surface temperature in the city of Cuiabá. Therefore, when we analyze two racial groups within the same city, we get different results with regard to the surface temperature data to which these groups are subjected.

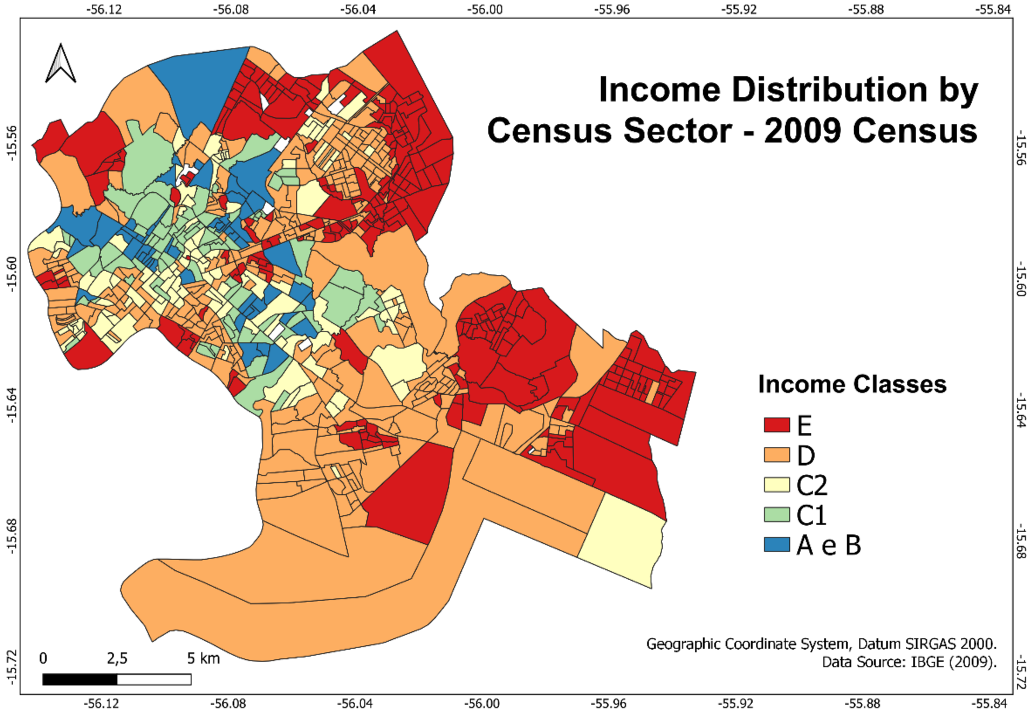
Figure 8 - Percentage of Black Population (A) and White Population (B) and the relationship between temperature by census sector for the urban area of Cuiabá.



Source: The authors (2024).

In order to understand whether there is a relationship between temperature and income distribution, we used data from the distribution by census sector (2009) of the population's income in the urban area of Cuiabá (Figure 9). The results showed that low-income households are located on the outskirts of the city, while high-income households are in the central part of the urban area.

Figure 9 - Income distribution map by census tract (IBGE, 2009)

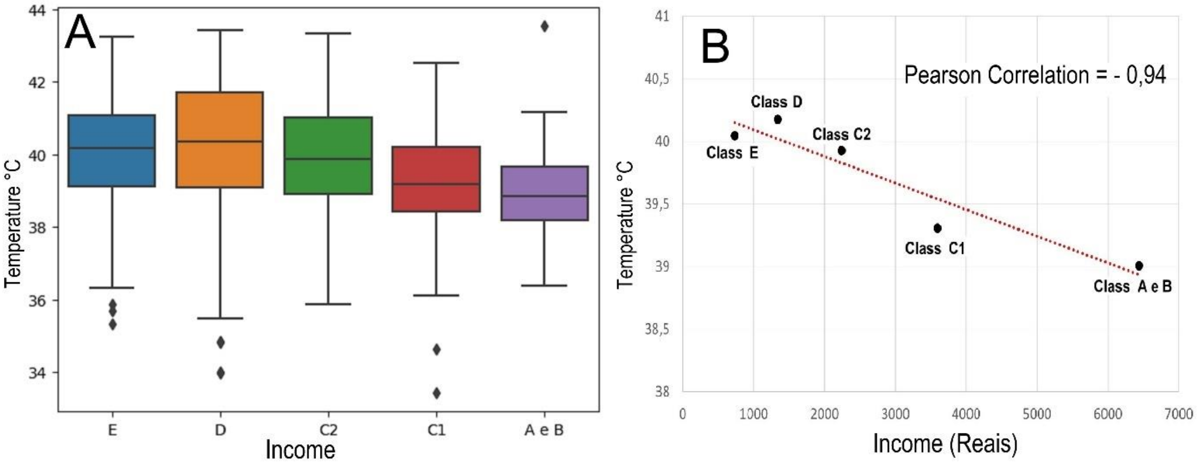


Source: The authors (2024).

Socio-environmental segregation in cities depends on the socio-economic, political and cultural reality of each country. In Brazil, the main type of segregation is socio-economic, where social classes are distributed unevenly in urban space, resulting in a dualized urban structure between the lower and upper classes, which control production and consumption, as is the case with the real estate market. Thus, the organization of the city reproduces inequality in relation to the distribution of power (Negri, 2008). This socio-economic inequality, found in several Brazilian cities, also affects the spatial distribution of surface temperature, as is the case in the city of Cuiabá, by cross-referencing information such as income and temperature, it is already possible to observe a significant inequality between the different social strata, where the low-income population suffers the most from the higher temperature conditions.

Thus, we can see that the higher the income, the lower the temperature to which the population is subjected, and the lower the income, the higher the surface temperature in the areas analyzed (Figure 10). The neighborhoods formed by classes E had one of the highest average surface temperatures compared to classes A and B and were also among the areas with the lowest NDVI values. The data shows a very high correlation value of -0.94 for the Pearson coefficient, indicating a strong relationship between surface temperature data and the population's income, with the negative sign indicating that the relationship between the variables is inverse, i.e. as the temperature rises, monthly family income tends to fall.

Figure 10 - Box plot between surface temperature and income data (A). Scatter plot showing the relationship between income and temperature by census tract for the urban area of Cuiabá (B)



Source: The authors (2024).

In their study, Velho and Fonseca (2015) related the temperature distribution to socioeconomic indicators for the city of Porto Alegre and found a strong correlation of -0.8 between maximum surface temperature and household income, with the negative sign indicating that the relationship between the variables is inverse, as increasing temperature decreases monthly household income. Another study, carried out by Cardoso and Amorim (2015) on the urban climate and socio-spatial and socio-environmental segregation in the city of Presidente Prudente - SP, analyzed the conditions of this population in the midst of climatic effects, concluding that the form of subdivision plays a large role in the thermal conditions, due to the removal of vegetation, the close proximity of houses built in agglomerations, and waterproofing with concrete, thus causing unhealthy conditions that affect the health of the population living there.

In order to establish the relationships between these variables, the result of the Shapiro-Wilk test initially showed that the data for the temperature variable does not follow a normal distribution (p-value = 0.0000003 / 3.276e-07) and indicates the need to apply non-parametric approaches to statistical analysis. Therefore, the non-parametric KW and GH tests were used to test the groups. The KW test indicated statistically significant differences between the social class/income groups in relation to the average temperature in Cuiabá (p-value = 1.584384e-09 / 0.000000001), suggesting that at least one pair of groups is statistically different in terms of average temperature.

In the specific test between the groups using the GH test (table 3), the results indicate significant differences in the median temperatures between groups A and B and groups C2, D and E. Group C1 is also statistically significant from the others (C2, D and E), indicating that the higher income classes (classes A and B) are concentrated in the regions with the lowest temperatures in the city of Cuiabá, regions with milder temperatures, possibly associated with better urban infrastructure and access to green areas. With regard to the lower classes (E, D and C2), there is no significant difference in temperature, but they are concentrated in the hottest areas of the city, in regions of lower thermal comfort. Therefore, the statistical analyses confirm the pattern of spatial segregation in the urban area of Cuiabá.

Table 3 - GH test results for the independent groups (income classes).

Test	A	B	median (A)	median (B)	difference	p-value	Hedges' g
1	A e B	C1	39.02	39.31	-0.29	0.76	-0.20
2	A e B	C2	39.02	39.93	-0.91	0.00	-0.62
3	A e B	D	39.02	40.19	-1.17	0.00	-0.64
4	A e B	E	39.02	40.06	-1.04	0.00	-0.72
5	C1	C2	39.31	39.93	-0.62	0.04	-0.41
6	C1	D	39.31	40.19	-0.88	0.00	-0.48
7	C1	E	39.31	40.06	-0.75	0.00	-0.50
8	C2	D	39.93	40.19	-0.26	0.63	-0.14
9	C2	E	39.93	40.06	-0.12	0.96	-0.08
10	D	E	40.19	40.06	0.13	0.89	0.08

Source: The authors (2024).

FINAL CONSIDERATIONS

The state of Mato Grosso is entirely in the tropical zone of the planet, so the population is subject to the hot climate which, added to the production model of urban spaces, is also a factor responsible for aggravating the high temperatures, a factor also responsible for aggravating high temperatures, causes the population thermal discomfort, which is further aggravated by the intense urban territorial expansion in the city of Cuiabá.

Although the NDVI values are more stable compared to the surface temperature values, it can be concluded that the surface temperature in Cuiabá over the last 36 years has increased with the influence of the growth of the urban area and the loss of vegetation cover. As a suggestion for future work, it would be interesting to also address the impacts of rising temperatures on a global scale as a result of climate change.

It should be noted that there is a strong relationship between surface temperature and vegetation in the city, i.e. areas with high surface temperatures are located in areas where there is little vegetation and the soil is more impermeable. An important observation should be made in relation to the center of Cuiabá (central core), which is between the East and West regions, and even though it is an area where NDVI values are less concentrated because it has more impermeable soil and a higher percentage of urbanization, the temperature in this region was not as high as in the other regions, bearing in mind that the resident population is mostly white people from classes A, B, C1 and C2, the population with the highest incomes in the city.

The urban areas identified with the highest temperatures are those described as peripheral and with the highest density, such as the following regions: in the North region, in the Morada da Serra neighborhood; in the East region, in the Alvorada and Porto neighborhoods; in the West region, in the Planalto, Carumbé and Pedregal neighborhoods; and in the South region, in the Pedra 90, Jardim Industriário, Tijucal, Nova Esperança, Osmar Cabral and São João del Rei neighborhoods. In terms of NDVI, the areas with the least vegetation cover are located in the northern region, specifically in the Morada da Serra neighborhood (outskirts), and in the central core of the city, between the eastern and western regions, also including all the aforementioned neighborhoods with the highest temperatures.

The type of construction and division of the land is different in the central core and in the peripheral area of the city, thus interfering with the temperature. In this way, the high surface temperature on the outskirts of the city is a consequence of the processes of inequality and socio-environmental segregation, where the majority of the population is black and low-income, unlike the neighborhoods of higher class and purchasing power, which are mostly white.

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