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Daytime and nighttime surface heat islands: a representative analysis of the dry and rainy seasons in Presidente Prudente – SP

Islas de calor superficial diurnas y nocturnas: un análisis representativo de las estaciones seca y lluviosa en Presidente Prudente – SP

Ilhas de calor superficiais diurnas e noturnas: uma análise representativa das estações seca e chuvosa em Presidente Prudente – SP

Giovanna Aparecida Souza Angeli [1] https://orcid.org/0009-0001-9053-8888
Margarete Cristiane de Costa Trindade Amorim [2] https://orcid.org/0000-0002-3975-493X

[1] Universidade Estadual Paulista, Presidente Prudente-São Paulo, Brasil, email: giovanna.s.angeli@unesp.br
[2] Universidade Estadual Paulista, Presidente Prudente-São Paulo, Brasil, email: margarete.amorim@unesp.br

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Abstract

The article addresses the formation of surface urban heat islands (UHIs), both daytime and nighttime, as a result of changes in land use and precipitation during the dry and rainy seasons in Presidente Prudente – SP. Remote sensing techniques and thermal images were used to measure thermal variations, generate UHI intensity maps, and calculate the Normalized Difference Vegetation Index (NDVI), an indicator of vegetation density and vigor. The results show that surface heat islands are more intense during the day and present significant variations between seasons, influenced by factors such as precipitation and temperature. In particular, the low precipitation observed in November contributed to the increase in temperatures, intensifying the impacts of UHIs.

Keywords: surface temperature; vegetation; precipitation; Presidente Prudente.

Resumen

El artículo aborda la formación de islas de calor urbanas superficiales (ICUs), tanto diurnas como nocturnas, en función de los cambios en el uso del suelo y la precipitación durante las estaciones seca y lluviosa en Presidente Prudente – SP. Se utilizaron técnicas de teledetección e imágenes térmicas, que permitieron medir las variaciones térmicas, generar mapas de intensidad de las ICU y calcular el Índice de Vegetación de Diferencia Normalizada (NDVI), indicador de la densidad y vigor de la vegetación. Los resultados muestran que las islas de calor superficiales son más intensas durante el día y presentan variaciones significativas entre las estaciones, influenciadas por factores como la precipitación y la temperatura. En particular, la baja precipitación observada en noviembre contribuyó al aumento de las temperaturas, intensificando los impactos de las ICU.

Palabras clave: temperatura de superficie; vegetación; precipitación; Presidente Prudente.

Resumo

O artigo aborda a formação das ilhas de calor urbanas superficiais (ICUs), tanto diurnas quanto noturnas, em função das alterações no uso da terra e da precipitação durante as estações seca e chuvosa em Presidente Prudente – SP. Para isso, foram utilizadas técnicas de sensoriamento remoto e imagens termais, que permitiram mensurar as variações térmicas, gerar mapas de intensidade das ICU e calcular o Índice de Vegetação por Diferença Normalizada (NDVI), indicador da densidade e do vigor da vegetação. Os resultados mostram que as ilhas de calor superficiais são mais intensas durante o dia e apresentam variações significativas entre as estações, influenciadas por fatores como precipitação e temperatura. Em particular, a baixa precipitação observada em novembro contribuiu para o aumento das temperaturas, intensificando os impactos das ICU.

Palavras-chave: temperatura de superfície; vegetação; precipitação; Presidente Prudente.

Introduction

Human interference on the planet's surface causes several changes in the climate. These changes are complex and, in order to understand them, it is necessary to consider the different scales of the climate. In order to analyze the urban climate, it is essential to understand both the regional context in which the city is located and the changes on the local scale, which are capable of generating heat islands (Amorim, 2020).

Therefore, this work seeks to analyze the intensities of surface urban heat islands (UHIs), daytime and nighttime, in periods representative of the dry and rainy seasons and to identify the characteristics of precipitation during the period when satellite images were captured in the city of Presidente Prudente - SP.

Presidente Prudente is located at 22º 07' 04" south latitude and 51º 22' 57" west longitude, with a population of 225,668 inhabitants (IBGE, 2022). Its climate is characterized by being tropical continental and is in a transition area between the tropical, polar and equatorial masses.

The climate in Presidente Prudente presents high temperatures for most of the year, with a concentration of precipitation in spring and summer and a significant decrease in rainfall events in autumn and winter. There is a prevalence of hot days, aggravated by urban territorial expansion and deforestation in the surrounding areas of cities (Sant'Anna Neto and Tommaselli, 2009), leading to an intensification of the generation of heat islands, consequently increasing thermal discomfort (Amorim; Dubreuil, 2016).

The urban climate can be understood as "a system that encompasses the climate of a given terrestrial space and its urbanization" (Monteiro, 1976, p. 23). The urbanization process in Brazil results from the articulation of economic, social, and political relations, and urban territorial expansion has triggered a series of urban "problems" (Sposito, 1989). This transformation in the geographic space in which the city is located, within a logic of capitalist reproduction, contributes to the fragmentation of urban areas.

In this context, the replacement of vegetation, changes in land use, and human activities contribute to the increase in temperature in cities, resulting in the formation of urban heat islands (UHI) (Amorim, 2020). According to the aforementioned author, UHI can be understood as a heat dome that surrounds cities.

The literature presents four types of heat islands, classified according to the layer where they form: 1 – the surface heat island diagnosed through remote sensing, which allows the calculation of the temperature of the targets (Oke et al., 2017); 2 – the lower atmospheric heat island, which Oke (1987) called urban canopy layer, between ground level and the average level of the roofs; 3 – the heat island of the upper urban atmosphere, called by Oke (1987), the urban boundary layer; 4 – subsurface (Oke et al., 2017). In the development of this work, the surface heat islands will be analyzed, allowing the calculation of the target temperature.

To analyze the surface ICU, it is necessary to use remote sensing techniques that assist in climate analysis, based on the processing of thermal images that allow the reading of the target temperature. The literature shows that surface temperatures present greater spatial and temporal variability during the day, compared to air temperatures, due to the different types of land cover (Baptista, 2012; Gartland, 2010; Weng, 2003; Lombardo, 1985; Mendonça; Dubreuil, 2005).

The use of these resources obtained through remote sensing contributes to research on the Earth's surface, allowing us to understand the distribution of heat sources in urban areas and the differences in relation to rural areas (Mendonça; Dubreuil, 2005).

Therefore, it can be said that the use of remote sensing in urban climate research is becoming increasingly important and necessary, occupying an increasing space in research on UCIs.

Current remote sensing systems provide essential data for understanding the dynamics of the Earth's surface, with applications in several areas, such as hydrology and geology, but mainly in cartography and urban studies.

Among the different uses of remote sensing, thermal images stand out, which capture surface heat and allow the identification of phenomena related to surface UCIs. For the present research, the images obtained through the Landsat satellite are the most important. This program consists of a series of satellites developed by the National Aeronautics and Space Administration (NASA), and is of great importance in understanding global changes (Novo, 2007).

According to Baptista (2012, p. 49), "when we think about thermal remote sensing we have to think about the thermal behavior of the targets", however, some factors can influence the emissivity of the targets on the Earth's surface. Since weather conditions constantly interfere with the surface temperature, modifying it in short time intervals and causing the data from the images obtained in the thermal band to show variations, it is necessary to consider the use and coverage of the land, as well as the types of weather of the locations to be analyzed.

Methodology

The theoretical and practical principles that support studies of heat islands in medium-sized cities, proposed by Amorim (2019), were used, together with a broad review of national and international literature on the theoretical and practical principles that seek to understand the formation of ICUs. In this scenario, remote sensing becomes essential for understanding the urban climate, especially the thermal characteristics of different urban and rural targets (Amorim, 2020). For Voogt and Oke (2003), surface temperature is the result of the effects of radiation on the surface and the thermodynamic properties of materials, including surface humidity, thermal emittance and surface emissivity, radiative input to the surface from the sun and the atmosphere, among others. Therefore, to achieve the objectives proposed in the work, daytime and nighttime satellite images from Landsat 8 and 9 in Presidente Prudente - SP were used, considering the absence of clouds over the research area as a criterion for choosing the images. These images were captured on the USGS (United States Geological Survey) website. Therefore, the possible time frame was the months of June and November 2022.

To process the images from the Landsat 8 and 9 satellites, formulas were used in a GIS (geographic information system) environment that transform the gray levels (NC) of a satellite image into radiance, then into Kelvin temperatures and degrees Celsius. The parameters and equations were obtained from the USGS website (https://www.usgs.gov/landsat-missions/using-usgs-landsat-level-1-data-product).

To create the UCI map, the intensity was calculated by subtracting the temperature pixels from the minimum temperature of the spatial cutout, that is, the vector cutout of the satellite image.

To better understand the characteristics of the analysis environment, whether by building density, vegetation density or land use, NDVI (Normalized Difference Vegetation Index) maps were also generated. The NDVI survey results in values ranging from -1 to 1, indicating the density, vigor and photosynthetic activity of the vegetation (Rouse et al., 1974).

Images from Landsat 8 and 9 satellites were used to prepare the survey, specifically bands 4 (red) and 5 (near infrared), which underwent the necessary mathematical procedures in software, thus obtaining the values for the selected scenes. The information collected in this action not only characterizes the areas studied, but was also used in the analysis to identify construction patterns. All of this data was processed using the QGIS 3.28 geoprocessing software.

To analyze the results of the surface ICU, the types of weather in the periods preceding the acquisition of the satellite images were identified, especially the volume of precipitation. The meteorological data were collected at the INMET (National Institute of Meteorology) meteorological station located at FCT UNESP.

Results and discussion

The results obtained from the thermal analyses, carried out during the day and night, as well as from the vegetation index, show the variation in the intensity of surface temperatures in different seasons of the year.

In June, the images were obtained on two different days: the daytime image on 06/27/2022 and the nighttime image on 06/29/2022. These dates represent the winter season, characterized in Presidente Prudente - SP, by presenting milder temperatures and lower precipitation totals. These aspects can be observed in the table of the sum of the precipitation volume in the 30 days preceding the imaging (Image 1).

During the day, greater intensity of ICUs is observed in the northern and central regions of the image, reaching a difference of 10.4ºC between areas with the highest and lowest temperatures. However, this scenario changes at night, since the northernmost area has low intensity, reaching 2.6°C, matching the intensity of environments with more vegetation, which have an NDVI of 0.4. (Image chart 1)

On the days when the daytime and nighttime images were taken, the air temperature (Table 1) at the FCT Unesp Meteorological Station, located in the intra-urban area of Presidente Prudente, characterized by a grassy area with some medium-sized and spaced buildings, at the time of imaging, the temperature was 19.3°C during the daytime (07/27/2022) and 16.6°C on the night of 06/29/2022. The intensities of the ICUs in this area were 7.8°C (daytime) and 4.1°C (nighttime).

Table 1 – Air temperature data on the day of imaging in June 2022

Air temperature recorded during the day 06/27/2022			Imaging schedule	Air temperature in the urban environment
Average Temp.	Maximum Temp.	Minimum Temp.		
18,8°C	25,2°C	13,5°C	10h	19,3°C

Air temperature recorded during the day 06/29/2022			Imaging schedule	Air temperature in the urban environment
Average Temp.	Maximum Temp.	Minimum Temp.		
20,1°C	24,6°C	16,6°C	23h	16,6°C

Source: INMET; 2024

In the month of November, characterized by the spring season, known for the increase in temperature and increase in the volume of precipitation, there are major differences in relation to the June images, since the highest intensities during the day and night were recorded in the urban environment, represented in figures 1 and 2 by the urban perimeter of Presidente Prudente. During the day, intensities that exceeded 12°C can be observed in the urban environment during the day and at night.

At the time of imaging, the air temperature (Table 2) was 31.2°C during the day and 22.1°C at night, with ICU intensity of 9.1°C and 10.9°C, respectively.

Table 2 – Air temperature data from the November imaging Day

Air temperature recorded during the day 11/10/2022			Imaging schedule	Air temperature in the urban environment
Average Temp.	Maximum Temp.	Minimum Temp.		
26,9°C	34,6°C	19,6°C	10h	31,2°C
Temperatura do ar registrada durante o dia 08/11/2022			Imaging schedule	Air temperature in the urban environment
Average Temp.	Maximum Temp.	Minimum Temp.		
22,5°C	29,6°C	15,2°C	23h	22,1°C

Source: INMET; 2024

Regarding NDVI, there is equivalence between vegetation, precipitation and ICU intensities, becoming a decisive factor for understanding what occurred in the months of June and November 2022.

The greater volume of precipitation 30 days before imaging in November (77.4 mm), compared to June (50.2 mm) caused vegetation to be more vigorous in rural areas in November than in June, resulting in the greatest difference in temperature between the urban area and its surroundings. With the greater volume of precipitation in November, vegetation developed and resulted in lower surface temperatures in areas with vegetation, compared to the densely built urban environment.

This is evidenced by the NDVI images (Image Chart 1 and 2). In June, vegetation had an NDVI value of 0.2 around the census sector, showing a lack of vegetative vigor. However, in November, with a higher volume of rain, the vegetation was more developed, with areas of 0.5 and other areas of 0.6 NDVI.

This fact directly reflected on the behavior of the ICUs, and the smaller differences between rural and urban areas (lower intensities) do not mean that the city was cooler, but that the countryside warmed up due to its vegetative behavior (Amorim, 2020).

Image Chart 1 – NDVI and intensity of surface heat islands in June 2022

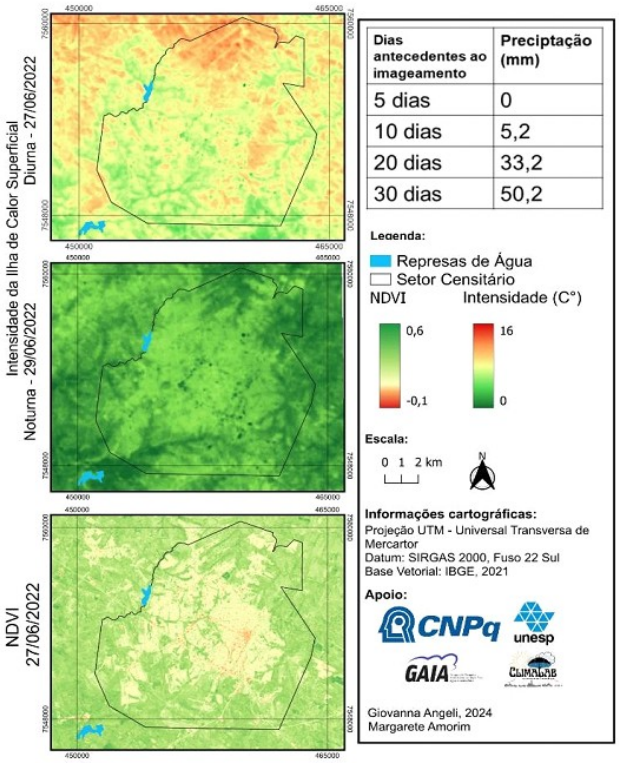
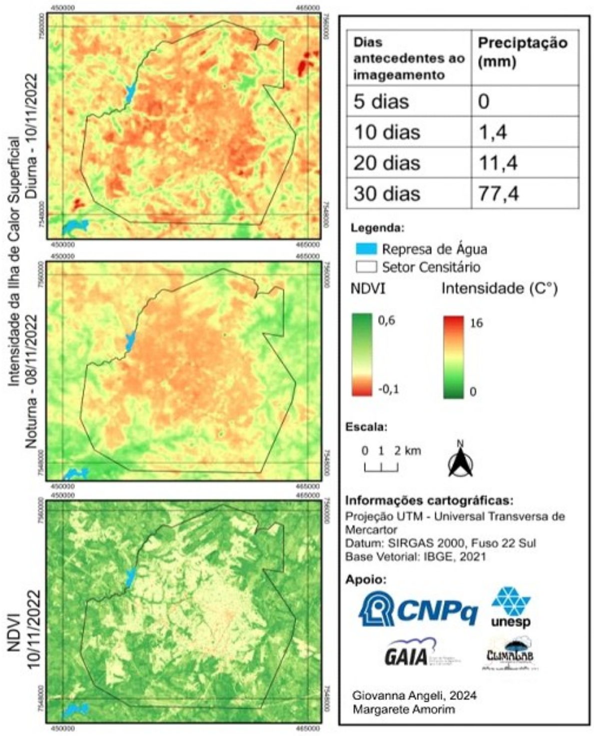


Image Chart 2 – NDVI and intensity of surface heat islands in November 2022



Source: Angelli; Amorim (2024), Landsat Image(2022)

By analyzing the intensity of the ICUs, it was possible to observe differences in the months representing the dry and rainy seasons, seeking to correlate the joint importance of vegetation and precipitation when talking about urban climate. As can be seen in the Letter images 1 and 2, the influence of precipitation on the temperature of the targets was evident, as also observed by Amorim (2020, p. 71):

> During heavy rainfall, the intensity of the surface urban heat island increases, because in rural areas the increase in biomass causes the target temperatures to fall. During the dry season, the intensity of the surface urban heat island decreases (compared to the rural period); however, intra-urban differences increase due to differences in the materials used in the roofs.

Furthermore, in image 2, the areas with the highest intensities during the daytime are the same as those at night. The work also coincides with other studies carried out by Miyakava (2023), who also analyzed Presidente Prudente in different months and years, but obtained similar results, which reinforces the addition of climatic elements and the interpretation of land use and occupation, since surface temperature alone does not fully support the discussion of its occurrence. Coltri et al. (2009) also identified that changes in land use and coverage, whether vegetated or urbanized, cause changes in the local climate.

Final Considerations

The results of this study highlight the complexity of the heat island phenomenon. Surface heat islands were more intense during the day, with significant thermal differences between daytime and nighttime periods, especially throughout the seasons. The distinct characteristics between October and November can be explained by the lower rainfall in November and higher temperatures, factors that directly impact urban thermal conditions.

It is clear that the distribution and density of buildings in urban areas contribute to heat retention, while the presence of vegetation cover and rural characteristics favor dispersion. This dynamic points to the need to consider urban planning as an essential tool to mitigate the effects of heat islands.

Urbanization strategies that incorporate increased vegetation cover, the use of construction materials that reduce heat absorption, and the expansion of green areas are essential to reduce excessive temperatures in cities.

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Author 1: Preparation, textual production and discussion of results
Author 2: Supervision, discussion of results, bibliographic research, text review