

Methodological proposal for evaluating the transformation of urban microclimate in medium-sized cities: a case study in the urban mesh of the municipality of Paracatu, Minas Gerais

Proposta metodológica para avaliação da transformação do microclima urbano em cidades de porte médio: um estudo de caso na malha urbana do município de Paracatu, Minas Gerais

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Abstract

The suppression of vegetation to increase built up areas intensifies the effects of urbanization and causes changes in the microclimate. Therefore, this research elaborates a methodological proposal to evaluate areas with potential for the formation of urban heat islands. Satellite images were used to verify the surface temperature and NDVI index of the study area. Mapbiomas usage and occupation data were also used. The city of Paracatu, located in the Brazilian Cerrado, was chosen for the application and validation of the proposed method. We used images from the LANDSAT-5 and LANDSAT-8 satellites, which initially underwent a resampling and standardization of the pixels. Subsequently, the surface temperature and NDVI calculations were applied, and these data were compared with the use and occupation. In general, it was possible to notice that there was, in the city, an increase in the average, minimum and maximum surface temperature. The same space-spectral behavior occurred for the NDVI, which are related to changes in land use and occupation. In relation to the areas with potential formation of urban heat islands, it was noted that these, in an interval of 14 years, tripled, being possible to relate the situation with urban expansion and the presence of new subdivisions in peripheral areas. It was also noted that the areas with mitigation potential for these were not planned, especially in the most populous neighborhood of the municipality. The results obtained were satisfactory and the proposed methodology may serve as a basis for public managers in relation to measures to mitigate the urban microclimate.

Keywords:

Surface temperature, NDVI, Urban heat island, Urban expansion.

Resumo

A supressão da vegetação para o incremento de áreas construídas intensifica os efeitos da urbanização e ocasiona alterações no microclima. Portanto, esta pesquisa elabora uma proposta metodológica para avaliar áreas com potencial de formação de ilhas de calor urbana. Foram utilizadas imagens de satélite para verificar a temperatura superficial e do índice NDVI da área de estudo. Também foram empregados dados de uso e ocupação do Mapbiomas. A cidade de Paracatu, localizada no Cerrado brasileiro, foi a escolhida para aplicação e validação do método proposto. Utilizou-se imagens dos satélites LANDSAT-5 e LANDSAT-8, que, inicialmente, passaram por uma reamostragem e padronização dos pixels. Posteriormente, foram aplicados os cálculos de temperatura da superfície e do NDVI, sendo esses dados, comparados com o uso e ocupação. De forma geral, foi possível notar que houve, na cidade, um aumento da temperatura superficial média, mínima e máxima. O mesmo comportamento espaço-espectral se deu para o NDVI, sendo esses, relacionados com as mudanças de uso e ocupação da terra. Em relação às áreas com potencial formação de ilhas de calor urbana, notou-se que essas, em um intervalo de 14 anos, triplicaram, sendo possível relacionar a situação com a expansão urbana e a presença de novos loteamentos em áreas periféricas. Notou-se também que as áreas com potencial de mitigação para com essas não foram planejadas, principalmente no bairro mais populoso do município. Os resultados obtidos mostraram-se satisfatórios e a metodologia proposta poderá servir de base para os gestores públicos em relação às medidas mitigadoras do microclima urbano.

Palavras-chave:

Temperatura da superfície, NDVI, Ilha de calor urbana, Expansão urbana.

I. INTRODUCTION

Regardless of their size, cities are generally characterized by the process of urban expansion in a disorderly way, causing changes in land use and occupation that negatively impact the environment. Therefore, mitigation and decarbonization actions, not carried out in this process, are now essential to reverse the changes in urban microclimate, their consequences and also to achieve the goal of the Paris Agreement. However, the way in which these effects are evaluated is still unknown to science.

The exposed situation becomes even more critical when analyzing the climate change report AR6 of the Intergovernmental Panel on Climate Change (IPCC), which indicated the anthropogenic influence on the increase of Greenhouse Gases (GHGs) in cities, which is closely related with changes in land use without their respective mitigations (IPCC, 2022; HE et al., 2022), being these, recognized as one of the most important challenges faced by today's society (SONG et al., 2020), because the alterations these alterations cause

variations in its Land Surface Temperature (LST) and, consequently, in the local microclimate, which science defines, through Monteiro (1976), as urban climate.

An efficient urban management capable of solving these problems becomes, increasingly, a pressing challenge for the managing bodies, since the negative impacts caused by the changes in the microclimate in the cities represent serious threats to their biogeochemical and biophysical processes, which leads to negative impacts on the ecosystem (SHEN et al., 2022) and, consequently, in the health of the population (PANNO et al., 2017; ZHAO et al., 2018).

Chan et al. (2012) related the increase in temperature to mortality and concluded that an average increase of 1° C in average daily temperature above 28.2° C is associated with an estimated increase of 1,8% in local mortality. Hua et al. (2023) analyzed the influence and effects of thermal discomfort on the mental health of the population, concluding that temperatures above 30° C cause detrimental effects on mental health. The authors also point out that this situation becomes even more critical when analyzing only middle-aged people, the elderly and women.

In addition to the above, when unplanned, the Land Use/Land Cover Change (LULC), as well as the intense increase in the LST, are capable of forming the Urban Heat Islands (UHI), which is worthy of mention in the scientific environment, especially given the way in which that these can be evaluated, measured and also mitigated (KAUR; PANDEY, 2022; LEE et al., 2022; WANG, 2022).

According to Xiong et al. (2022), the growing search to solve this problem may be related to improvements in geoprocessing techniques and the ease of working with satellite images, which, when compared to in situ measurements, such as ambient temperature, have the advantage of performing low-cost and large-scale monitoring, being essential for effective decision making (PAVÃO et al., 2017; SANTOS et al., 2022). However, it is noteworthy that meteorological parameters, such as wind displacement speed and air temperature, directly affected by topographic variations imposed by buildings, even today, are strong allies for a more accurate diagnosis of the UHI (LEAL FILHO et al., 2017).

Given the above, research reports a positive correlation between the increase in LST with the growth of urban areas, as well as a negative correlation between LST and green areas, which are measured using the Normalized Difference Vegetation Index (NDVI). For example: the vegetation has the role of mitigating the high temperatures caused by the alteration of the vegetation cover by impermeable surfaces (KARAKUŞ, 2019; HUA et al., 2020; YANG et al., 2020). However, how do you find areas that have been impacted by this change and that currently have the potential to form UHI in these locations?

Given the definitions of Oke (1978) and Arnfield (2003), as well as the recognition of the authors of the formation of the 3 distinct types of UHI, namely: a) low atmospheric; b) upper atmosphere and; c) of the surface, the present work aims to propose a method in which it is possible to evaluate monitoring points for possible UHI formations in medium-sized cities and apply it, in order to verify its spatio-temporal variation, in order to present new paths for geographic climatology, which is the justification for this research, since cities such as Paracatu present remarkable economic growth, providing a representative increase in the national scenario. In addition, they have considerable facilities for the identification of their intra-urban landscapes, allowing a better understanding of the society-nature interaction in the construction of the urban climate.

II. MATERIALS AND METHODS

Study area

Located 220 km from the federal capital, Brasília - DF, Paracatu - MG (Figure 1), it belongs, in its entirety, to the Cerrado biome, being a national highlight in tourism, mineral wealth and agriculture. According to the latest estimate from the Brazilian Institute of Geography and Statistics (IBGE), the municipality has a current population of approximately 94 thousand inhabitants and a population density of 10.29 hab./km² (IBGE, 2022).

Paracatu has an altitude between 500 and 950 meters and is located between two hydrographic basins: São Francisco and Paraná. Its urban area is situated between 650 and 800 meters. According to the Köppen classification, the climate of the municipality is humid tropical savannah, with dry winters and rainy summers, type Aw. Its average annual temperature is 22.6 °C, and its average precipitation is 1.450 mm/year (INMET, 2022).

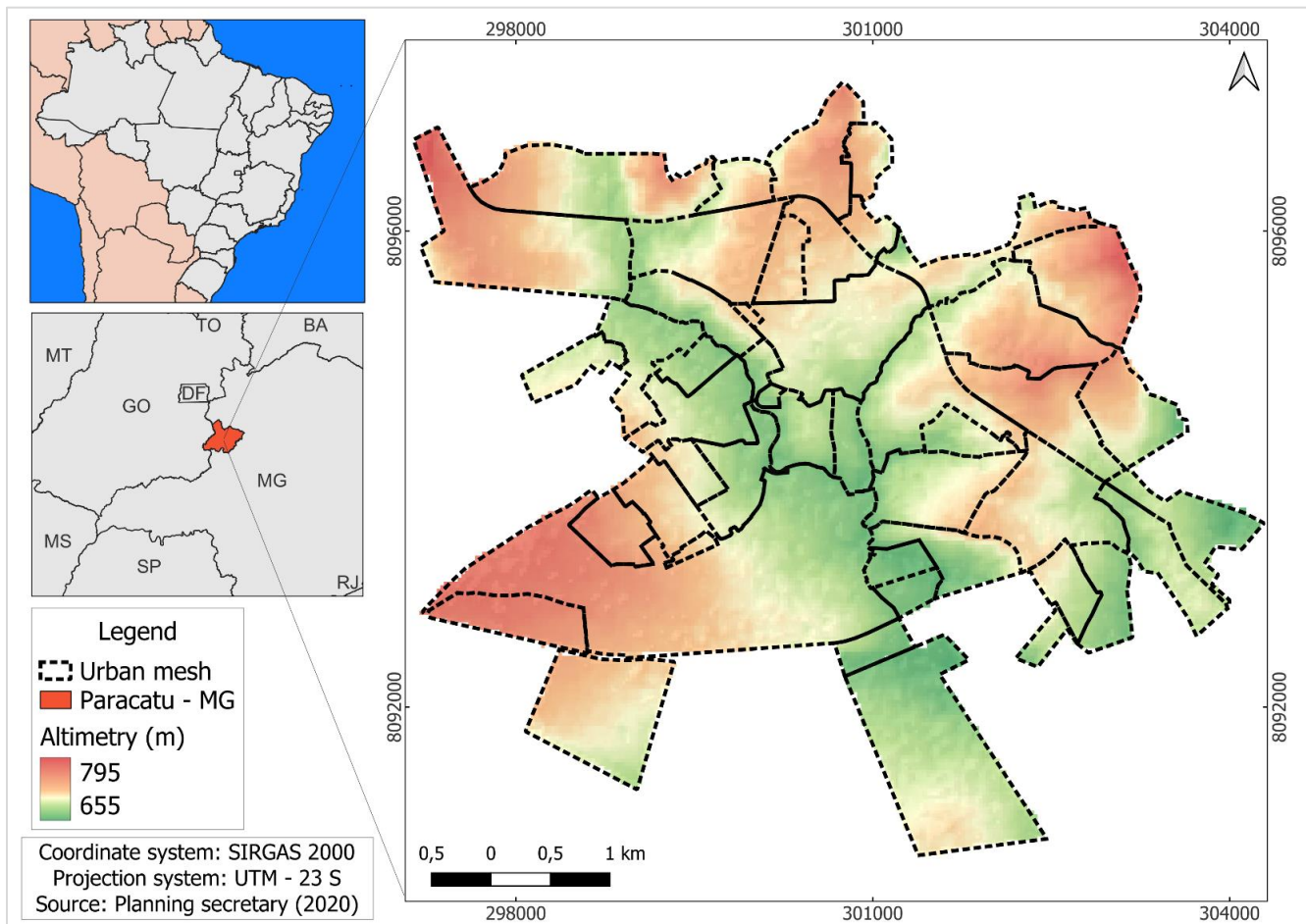


Figure 1 - Study area. (Source/The authors, 2020)

Methodological procedures

Scenes from the LANDSAT-5 and LANDSAT-8 satellites, obtained from the United States Geological Survey (USGS) website, were used. In this study, we opted for the analysis of years considered normal, that is, in which there was no occurrence of El Niño and La Niña phenomena, given the influence of these phenomena on climatological parameters and, consequently, on the LST (NUNES; GIGLIO, 2022; UDELSMANN, 2022), this being the first highlight presented by this research. The second relevance of this method concerns the average of the images chosen, that is, for each chosen period, the average of the 2 images was used to represent the season of the year, thus avoiding questions about the representativeness of studies involving Remote Sensing (RS) data.

As a justification of the years chosen for the analysis of the present study (2005 and 2019), we sought to analyze years in which it was possible to explore a minimum period of ten years of difference, considering that, in this space of time, it was possible to verify a considerable urban expansion in the study area. In the year 2005,

the images of 11/04 and 13/05 were used, while, for the year 2019, the images 02/05 and 21/06 were chosen (USGS, 2022).

Regarding the season chosen for analysis, this is due to the following factors: a) greater neutrality of soil water availability; b) low incidence of clouds; c) season that separates the wet period, with possible water surplus in the soil, such as the dry one, from possible water stress. After downloading the satellite images, the Resampling and Reducing Resolution process was used, with the nearest neighbor technique, of the QGIS 3.2.12 software (QGIS, 2021) to standardize all the pixels of the different satellites used (30 meters).

To calculate the NDVI index, the equations and recommendations suggested by Rouse (1973) (Equation 1) were applied, while for the LST, the suggestions from the USGS (2022) (Equation 2) were used. To apply the respective methods, the raster calculator of the Qgis 3.2.12 software (QGIS, 2021) was used.

Regarding the calculation of the LST of the LANDSAT-8 satellite, the value of -0.29 was added for each pixel of the resulting image of the average, as recommended by the USGS, since the thermal bands 10 and 11 receive interference from scattered light from areas adjacent to the imaged scene and therefore require this adjustment. USGS recommends using band 10 when estimating LST (USGS, 2022).

$$\frac{(\text{NIR } \rho_{(830\text{nm})} - \text{RED } \rho_{(660\text{nm})})}{(\text{NIR } \rho_{(830\text{nm})} + \text{RED } \rho_{(660\text{nm})})} \quad (1)$$

Equation 1: calculation of the NDVI index.

Where: NIR corresponds to the near-infrared band and RED corresponds to the band located in the red region.

$$T = \left(\frac{K2}{\ln \left(\left(\frac{K1}{ML * Q_{cal} + AL} \right) + 1 \right)} \right) - 273.15 \quad (2)$$

Equation 2: LST calculation.

Where: ML = Thermal band scaling multiplicative factor*, AL = Thermal band specific additive scaling factor*, Q_{cal} = Pixel-calibrated quantized value in DN, T = temperature in Celsius, K2 = calibration constant 2* and K1 = calibration constant 1*.

*Values used in image processing (obtained from the metadata file).

Regarding the land use and occupation data for the city of Paracatu, it was decided to use the data already validated by the Mapbiomas Annual Land Use and Coverage Mapping of Brazil, which brings together a collaborative network in the areas of RS, biomes, land use, GIS and computer science. This project uses cloud processing and automated classifiers, allowing the generation of a historical series of annual maps and land use in Brazil through the LANDSAT satellite, with a spatial resolution of 30 meters (MAPBIOMAS, 2022).

With all processed, a mask of the study area was used to cut out the area of interest, this being in Shapefile format (.shp) and representing the reality of the urban mesh of the municipality. This file was obtained from the Planning secretary of the municipality of Paracatu and with a scale of 1:50000. After cutting the parameters for this, the files were exported to the ArcGis (10.5) software (ESRI, 2022) to perform the join of the attribute tables containing the results of the respective indexes.

Aiming to verify areas with potential for formation of UHI, a rule was elaborated, based on correlated studies, in the raster calculator (Figure 2). At this stage, it should be noted that the cutoff values of the NDVI index and the LST were performed based on correlated results involving the evolution of the urban climate (GAMEIRO et al., 2016; MURTINOVA et al., 2022; FLOYD; RUTH, 2022; CHOWDHURY; ISLAM, 2022).

Finally, and in order to verify the influence of areas with potential formation of UHI on the urban climate of the city of Paracatu, a spectral-temporal comparison of the NDVI and the LST of the areas was carried out through data analysis with potential formation of UHI towards the other areas of the city.

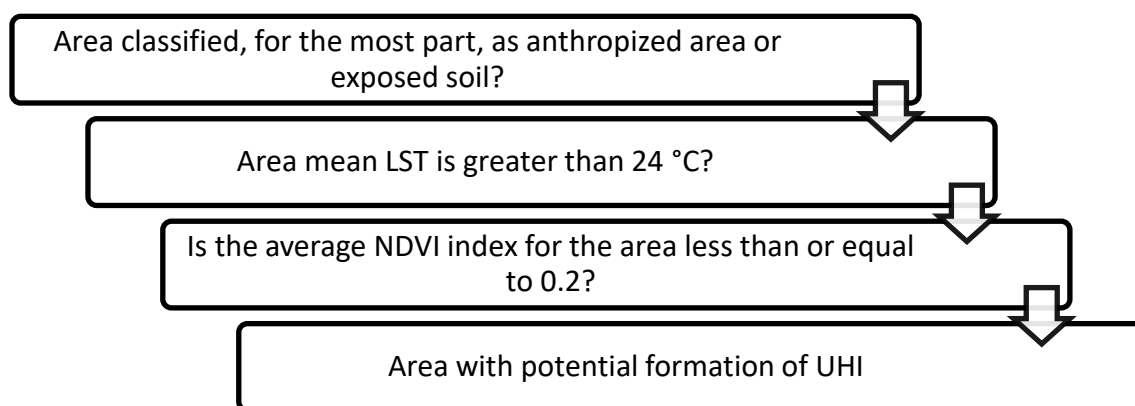


Figure 2 - Method used to verify potential formation of UHI. (Source/The authors, 2022)

III. RESULTS AND DISCUSSIONS

Figure 3 presents the spatio-temporal behavior of the LST in the city of Paracatu and, Figure 4, the NDVI. In Figure 5, the behavior of the pixels for the referring parameters is displayed and, finally, in Figure 6, the LULC of the urban mesh of the municipality.

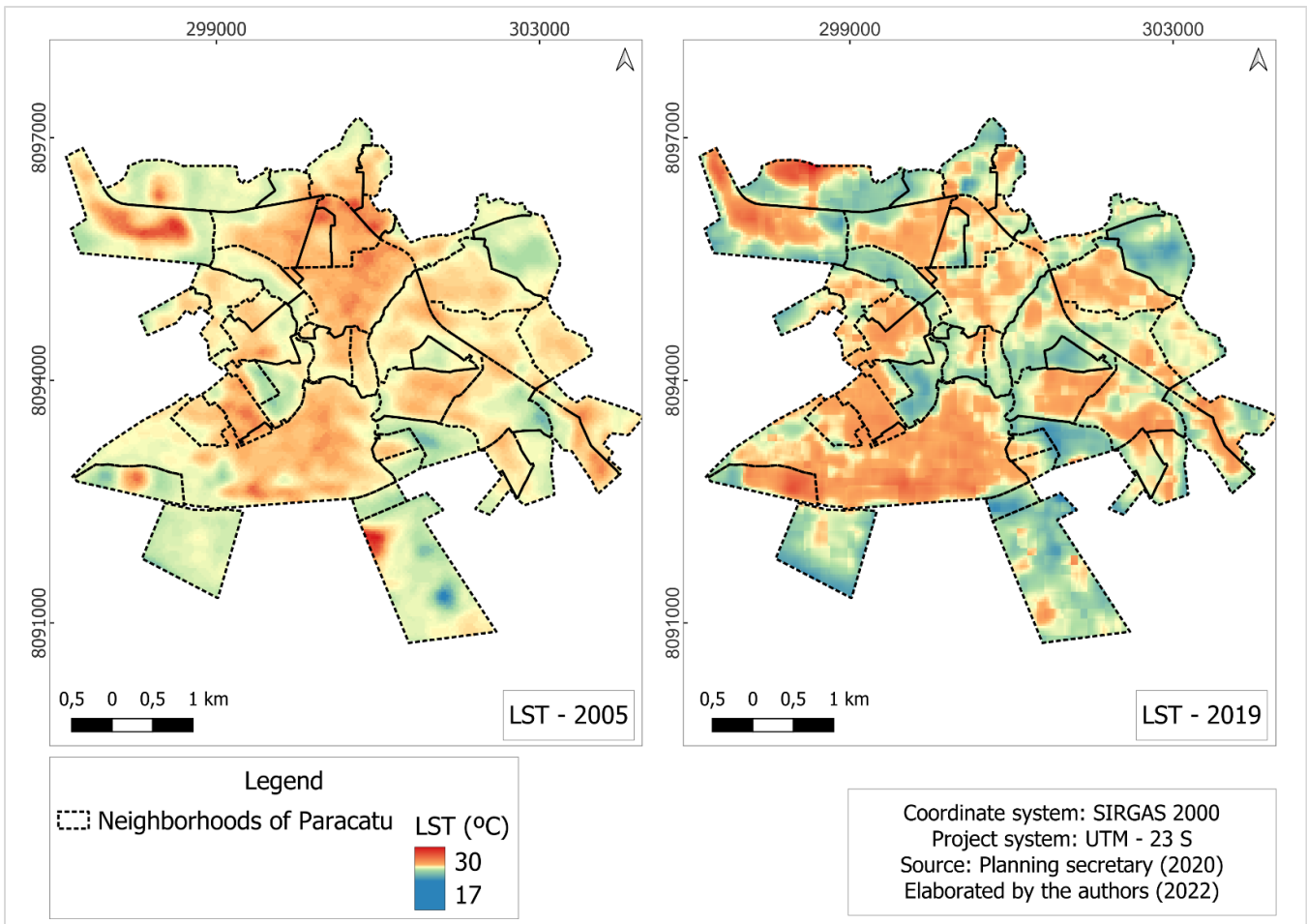


Figure 3 - Spatial-temporal variation of LST in the urban mesh of Paracatu – MG. (Source/The authors, 2022)

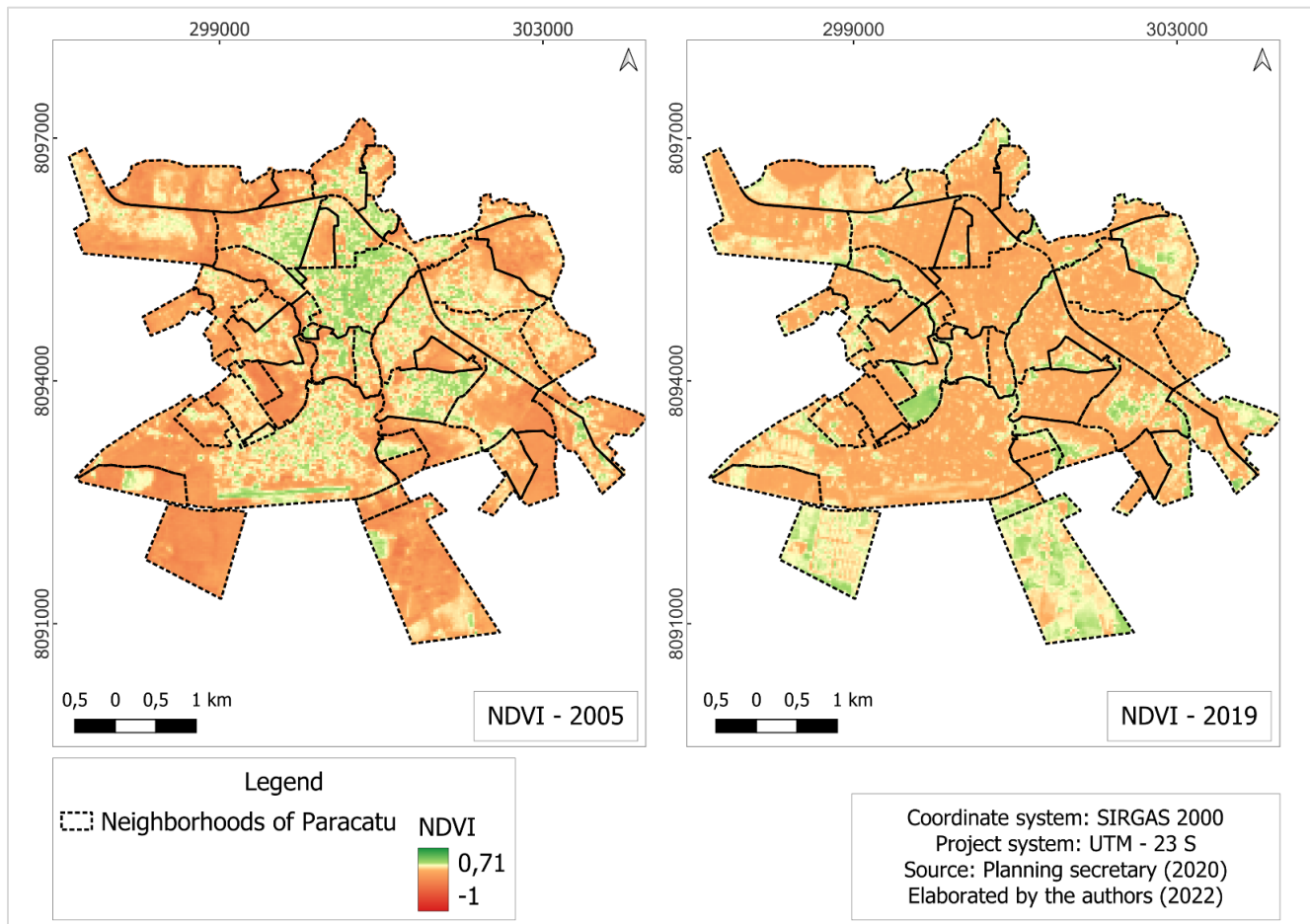


Figure 4 - Variation of the NDVI index in the city of Paracatu – MG. (Source/The authors, 2022)

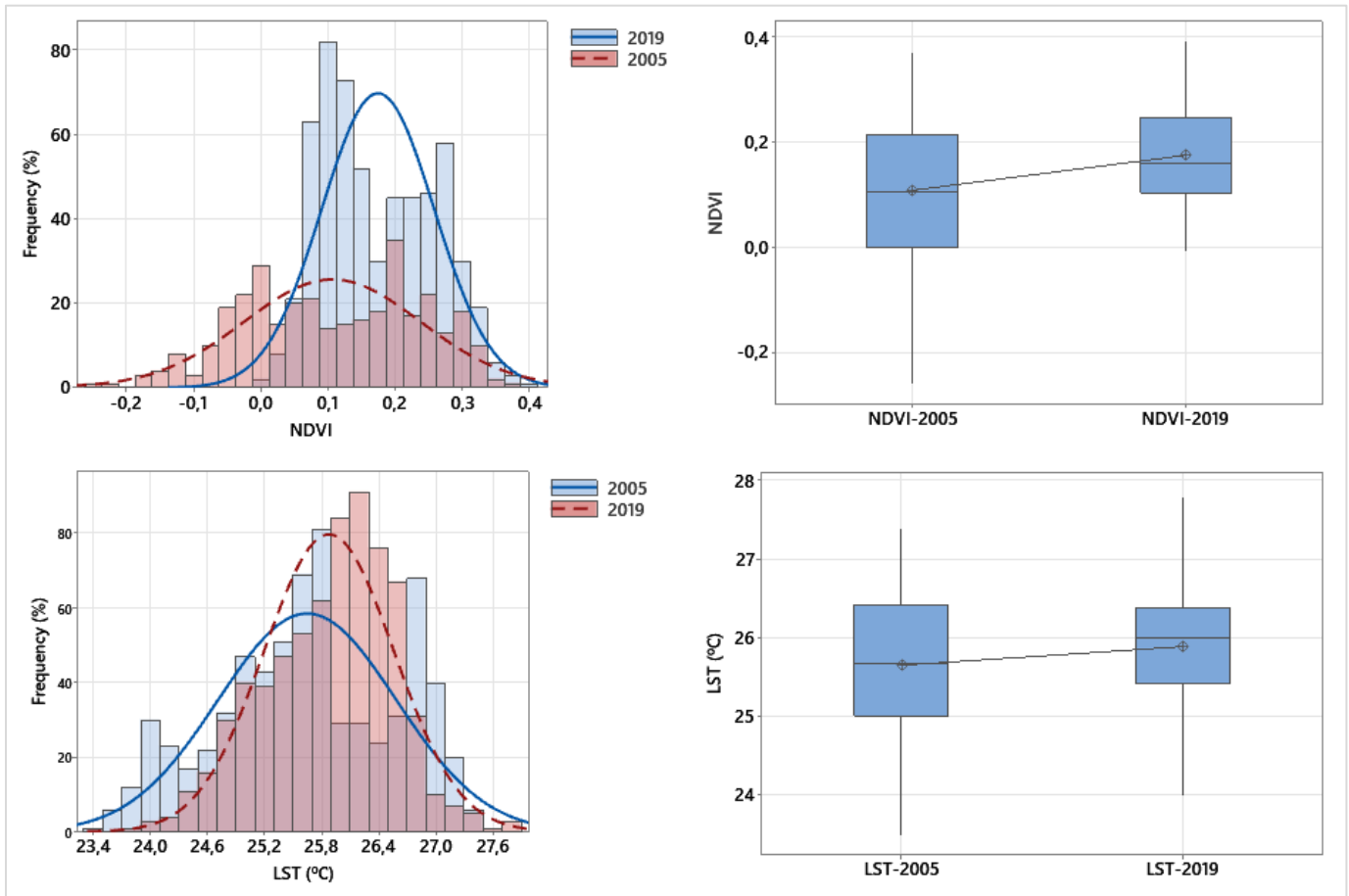


Figure 5 - Space-spectral behavior of the NDVI and LST indices. (Source/The authors, 2022)

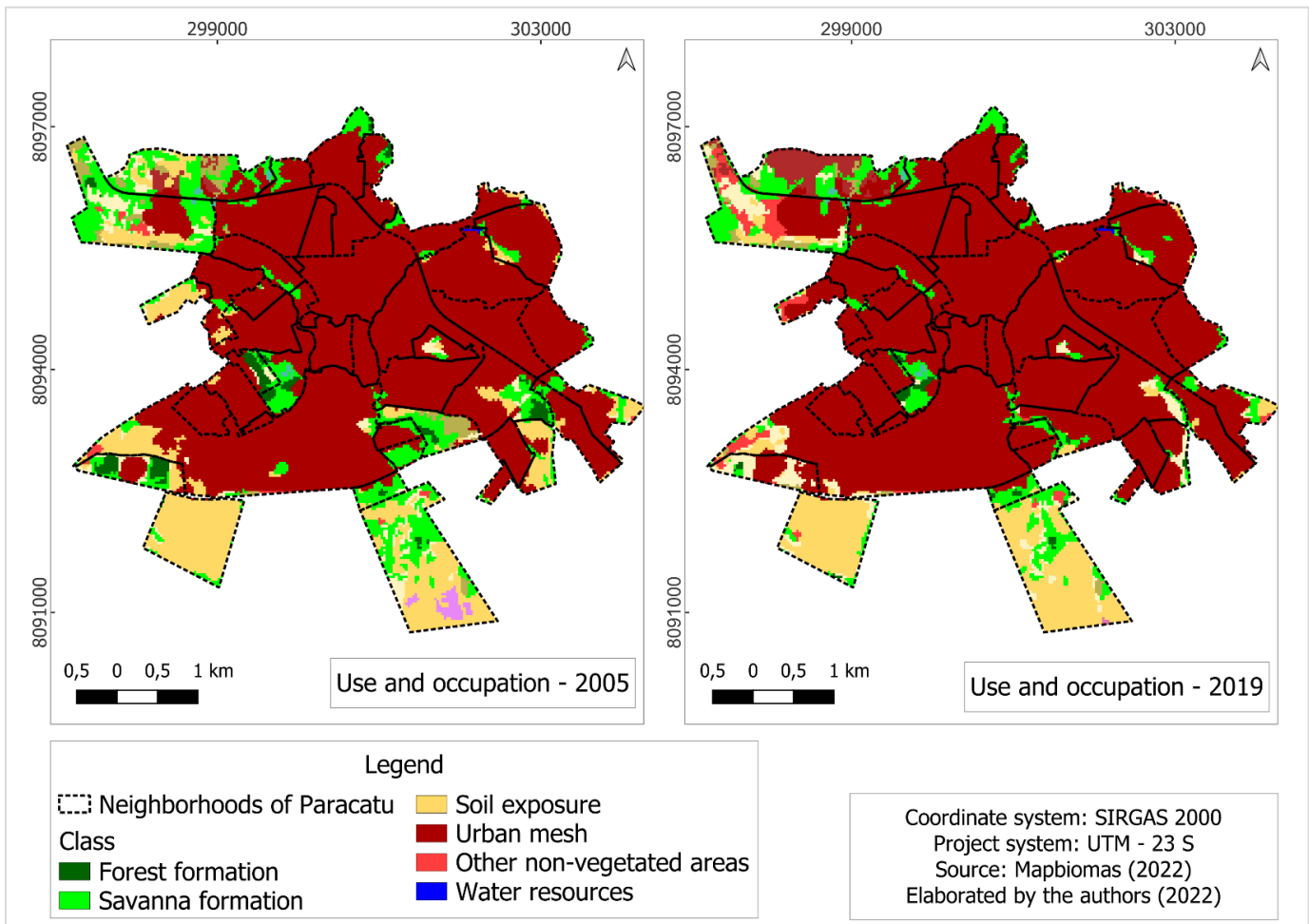


Figure 6 - LULC of the urban mesh of Paracatu – MG. (Source/The authors, 2022)

In general, it is possible to notice that, when comparing spatio-temporally, both parameters analyzed – NDVI and LST – had an increase in their average, minimum and maximum. When comparing these data with the LULC, it is clear that urban sprawl interferes with them. It is important to mention that the increase in LST in urban areas is closely related to the presence of built-up areas and/or the presence of exposed soil (uncovered land), which are the main responsible for the temporal variation of this parameter (GUHA; GOVIL, 2018).

In view of the analysis of the influence of the variation of the LULC on the LST, the importance of vegetation to neutralize and/or reduce this impact is mentioned, given studies that mention the negative correlation between the LST and the NDVI. For example: areas with dense vegetation and NDVI above 0.5 have milder LST, while areas with low NDVI, related to the presence of thick vegetation and/or the absence of green areas, have higher temperatures (MATHEW et al., 2022; MOISA et al., 2022).

It is also worth discussing that the city of Paracatu has a high rate of floating population and/or fixed migration, given the presence of multinationals in the exploration and processing of ore in the city. In addition,

the municipality is prominent in the production of grains, which attracts industries and, consequently, new employees to the city. For example: given the fact that Paracatu has such characteristics in terms of employment opportunities, the migratory flow and the occupation of new areas in the city are intense and, over the years, these changes are becoming more spatializing, and these changes are already possible. observation via LULC map.

In this perspective, Rezende (2016) verified, in the urban mesh of Paracatu, that the recent sectors have a lack of vegetation on the sidewalks, which should not occur, since the municipality has, since 2009, the obligation to plant trees on the sidewalks public in the new buildings, which is the responsibility of the landowner after obtaining the permit – Habite-se – for construction on the land.

It can be seen that, no matter how much public management performs its function, it is not strictly adhered to by the residents. In this way, the use of satellite images with high spatial resolution, as well as the use of drone images, could be used, in the city, for the purpose of monitoring compliance with current municipal legislation.

The areas with potential formation of UHI in the analyzed years are arranged in Figure 7 and, in Figure 8, the areas of intersection, that is, they showed potential formation of UHI in 2005 and 2019, which are considered as monitoring areas. The space-spectral behavior of these areas for the NDVI index and the LST is shown in Figure 9.

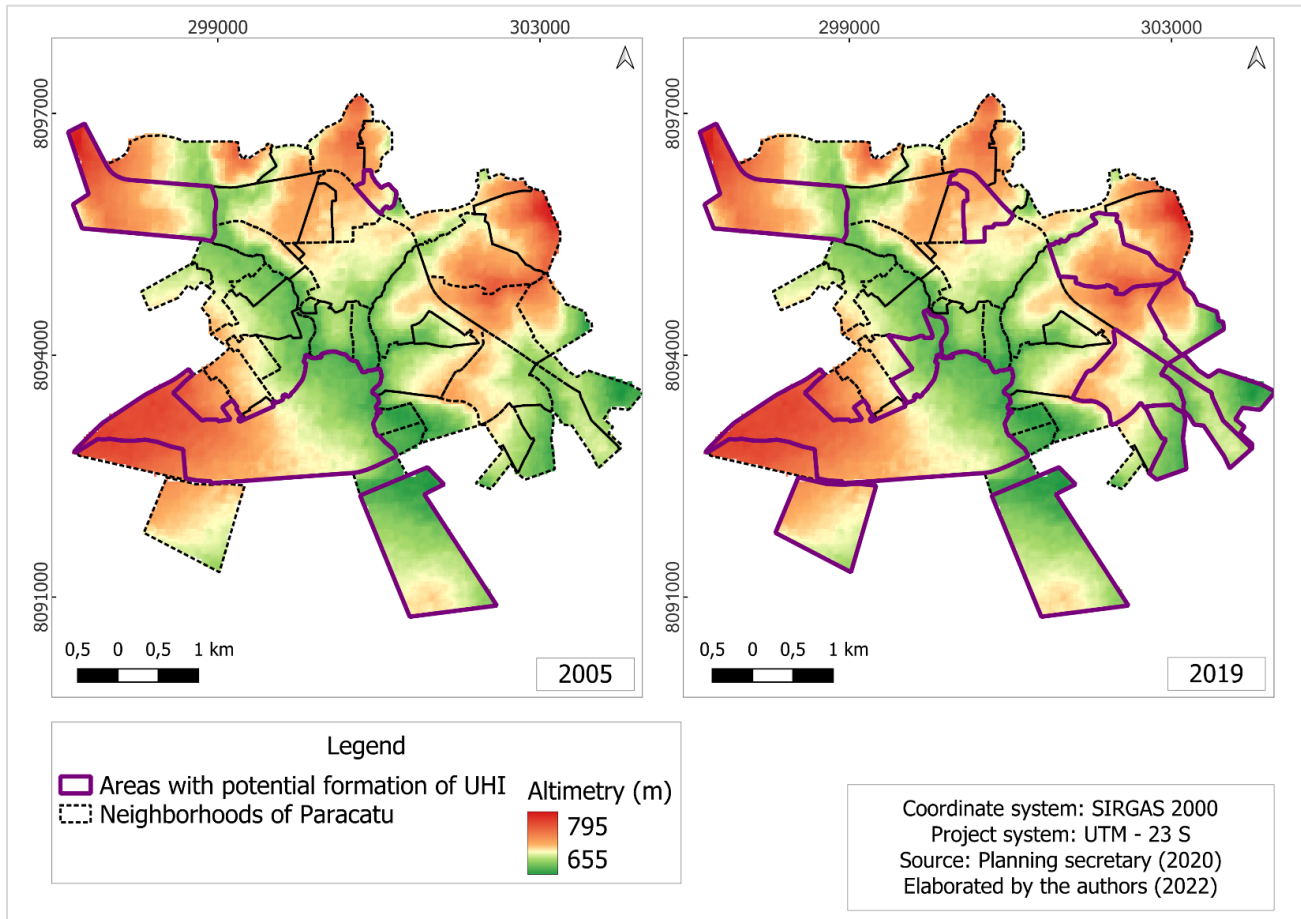


Figure 7 - areas with potential formation of UHI. (Source/The authors, 2022)

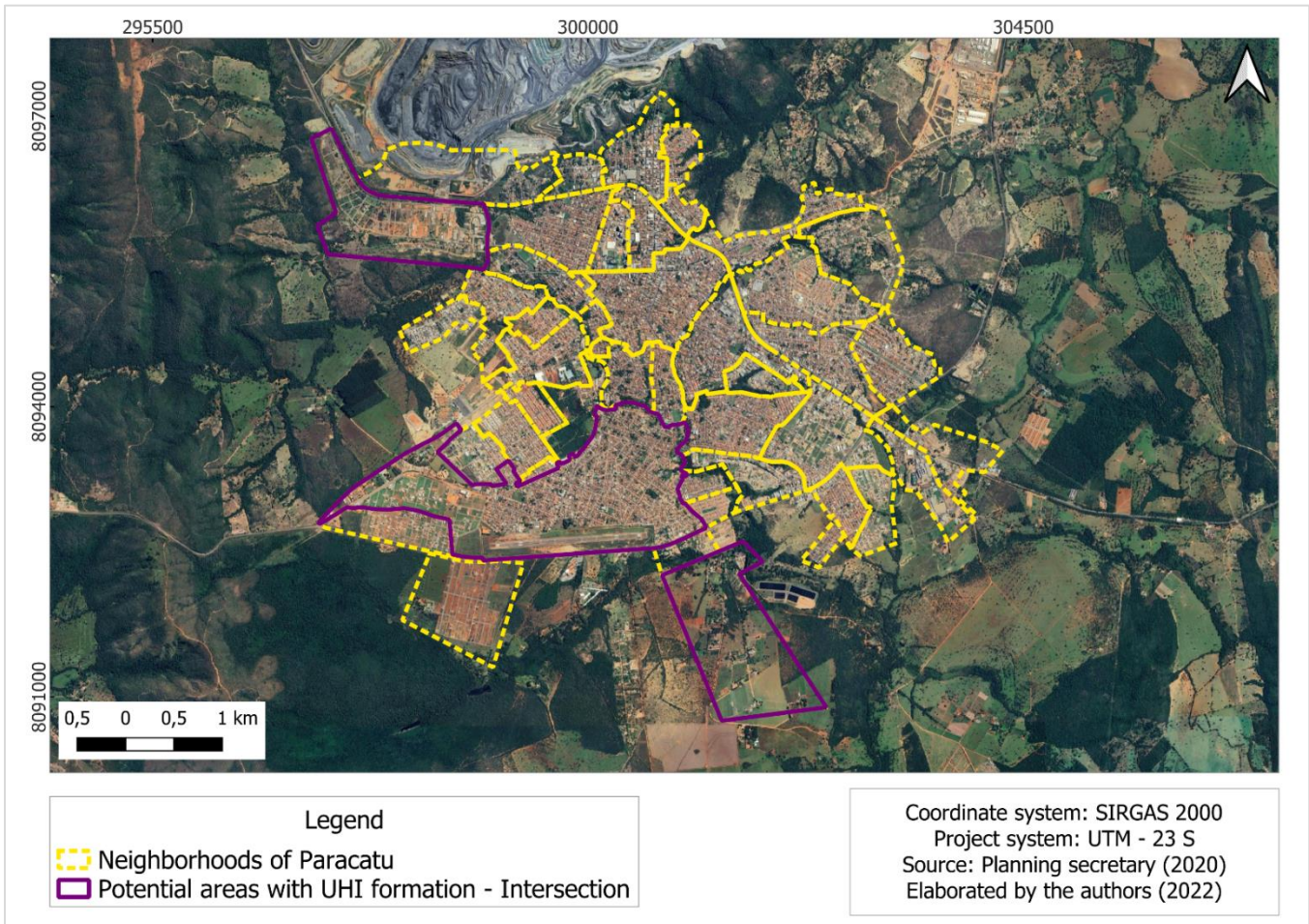


Figure 8 - Monitoring areas (UHI). (Source/The authors, 2022)

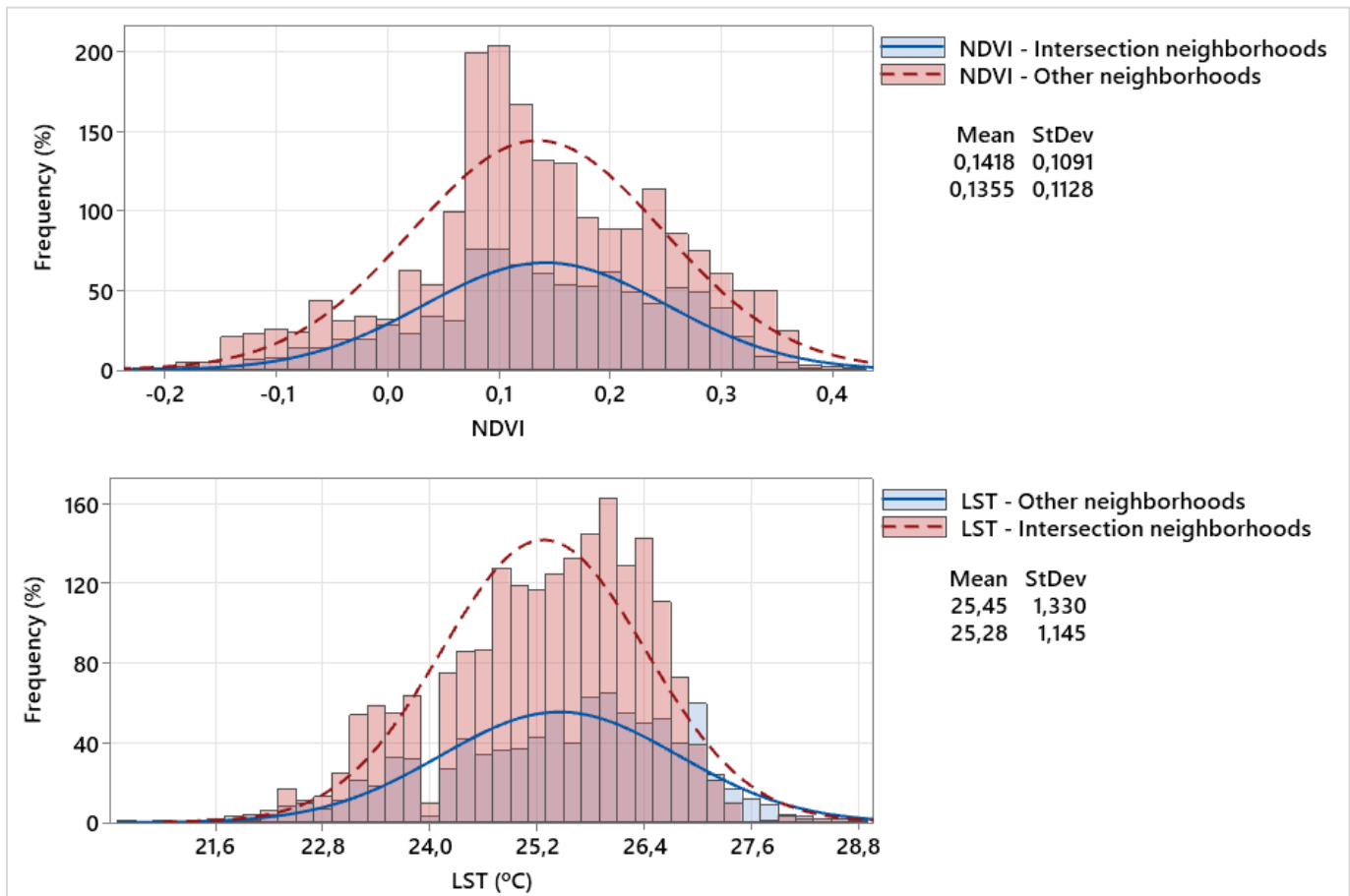


Figure 9 - Space-spectral behavior of areas with potential formation of UHI. (Source/The authors, 2022)

In general, it is possible to verify, in relation to the spatiality of the areas with potential formation of UHI, new formations in peripheral areas of the city of Paracatu. In addition, within 14 years, the number of areas with potential UHI formation in the city tripled, from 4 to 12.

The scenario described can be explained by several factors. Among these, the formation of numerous allotments in the city during the last decade stands out. Faced with urban sprawl, the city began a process of growth towards the outlying areas, hitherto unoccupied. For example: from the moment the permit for the start of the works is approved, the vegetation is removed for the start of sales and construction on the lots. Thus, it is noted that this LULC, without the appropriate mitigating measures, is directly implicating the urban microclimate of Paracatu.

Another factor to be mentioned is that the cost of housing in the municipality is quite high. In this way, and in view of the migratory and/or fixed flow of new workers who enter the city, residences in peripheral areas, and even in new built allotments, become attractive for new habitants, who choose to live in more distant places. This scenario is corroborated by verifying the time series shown in Figure 10.



Figure 10 - Neighborhood with potential formation of UHI (40) in 2003 (a) and in 2019 (b). (Source/The authors, 2022)

Historically, the city concentrated all its services – shops, hospitals, pharmacies, banks and leisure options – in the municipal urban center. However, according to information collected on the city's website, aiming, among other factors, to improve the flow of the urban center, both the city hall and all its executive demands were transferred to an administrative center, located in a peripheral area in the last decade. Currently, it is also possible to verify the installation of banks in the districts of the municipality, easing the flow of the urban center, especially at rush hour.

In relation to the neighborhoods that presented potential for the formation of UHI in the two years analyzed, the neighborhood popularly known as Paracatuzinho stands out, which is the most populous in the city. Data from the National Census Service for the year 1960 already showed that, at that time, the population of the neighborhood was larger than that of the city center, according to Lima (2019), who highlighted in his study that, according to a spreadsheet obtained from the Municipal Secretariat of Endemics, the area had 5.369 buildings, surpassing even the center of Paracatu, which accounted for 2.188 properties for the same period.

In view of this, it is possible to infer that the urban expansion, in an unplanned way, of the 'Paracatuzinho' neighborhood is closely related to the variation in the LST of the area. In addition, this disordered local growth most likely occurred without mitigation for the local microclimate, directly impacting on possible UHI formations.

In view of the spectral behavior of the parameters analyzed in the areas that presented potential formation of UHI in both analyzed periods, it is possible to notice that, when analyzing these areas separately, they are responsible for representing a large percentage of the behavior of the city as a whole. Thus, from the

moment that the impacts caused to these are mitigated, most likely, the behavior of the LST, as well as the effects of UHI, will be minimized in the city.

The results presented corroborate those presented by Albuquerque and Lopes (2016), who verified the influence of vegetation on climatic variables in some neighborhoods in the city of Teresina, Piauí (PI), concluding that these, among other factors, help in local climatic conditions, being extremely importance for the improvement of environmental quality in urban agglomerations, mitigating the effects of UHIs.

The results verified for the city of Paracatu corroborate the fact that the NDVI index, as well as the variation of the LST and the use and occupation of the land, become, increasingly, a notorious tool for monitoring the urban climate (SINGH et al., 2022). Thus, reforestation and afforestation practices in public areas must be urgently used as a way of mitigating the impacts caused by LULC, as well as strategies to minimize the negative impacts caused by new occupations, as these measures may, as mentioned by AlDousari et al. (2022), reduce the negative impacts of climate change and the possible formation of UHIs.

The aforementioned strategy is corroborated by verifying the study by Silva and Pimentel (2019), conducted in Recife, Pernambuco (PE), in which the authors verified the contribution of different vegetative species to the thermal confrontation, concluding that the trees with the largest leaf area were the ones that most absorbed solar radiation, presenting great importance in maintaining the quality of life in the cities. The importance of urban afforestation was also verified by Silva et al. (2020), being the main contributor to the microclimate in Caicó, Rio Grande do Norte (RN), located in the Brazilian semiarid region, ratifying the importance of trees in the face of changes in the urban microclimate and relative humidity.

IV. CONCLUSIONS

The results show that the city of Paracatu presents growth in areas with potential for the formation of UHI. Thus, mitigating measures, such as the creation of green areas, should be developed in these places.

In relation to areas with potential formation in both years analyzed, it was inferred that population expansion and disordered urban occupation were the main factors that influenced these results.

The proposed method, given its temporal and spatial-spectral validation, proved to be efficient for monitoring areas with potential for UHI formation, and can be used for the management of urban microclimate in medium-sized cities, being useful to public managers and decision makers.

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