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GEOSCIENCES

The influence of urban and mineral expansion on surface temperature variation

Arthur Pereira dos Santos[1], Fernando Luiz de Paula Santil[2*], Samara Carbone[1] and Claudionor Ribeiro da Silva[2]

[1]Instituto de Ciências Agrárias, Universidade Federal de Uberlândia, Rua Acre, 1004, 38405-325, Uberlândia, Minas Gerais, Brazil. [2]Instituto de Geografia, Universidade Federal de Uberlândia, Uberlândia, Minas Gerais, Brazil. *Author for correspondence. E-mail: santil@ig.ufu.br

ABSTRACT. This study addresses the variations in surface temperature - Land Surface Temperature (LST) - in the urban network of the municipality of Paracatu, Minas Gerais State, Brazil, which has humid tropical climate of savannah (type Aw), and in the open pit mining activity located near its urban perimeter, between the years 1990 and 2019. The area was chosen because the municipality is the most important of its microregion, being an attractive pole of work due to the presence of several companies, with emphasis on the mining company Kinross Gold Corporation, which is one of the largest open pit mines and gold producers in Brazil. Images of LANDSAT-5 and 8 satellites were used, which underwent a resampling and standardization of pixels to become the same size. The satellite choice and the period of analysis was based on the beginning of mining activity in the municipality, and a year that was able to represent its current state. Subsequently, the LST calculations made available by the United States Geological Survey (USGS) were applied. When comparing the results of both areas of the first and last year of the series, there was an increase in the variation of the mean, minimum and maximum LST, a fact that is related with the suppression of vegetation for the growth of both areas. Such suppression, together with anthropic occupation, is responsible for one of the neighborhoods (28) that present the highest average variation of LST over the years. On the other hand, the neighborhood that presented the smallest variation on this parameter (47) was recently incorporated as a neighborhood in the city's Master Plan because it is currently being occupied by the construction of an allotment, evidencing that the temporal variability of LST in the municipality occurs in relation to anthropic presence and its magnitude.

Keywords: landsat; LST; NDVI; urban expansion; heat islands.

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Introduction

Cities are characterized by climatic particularities resulting mainly from interferences and energy exchanges between the surface and the atmosphere (Moreira & Amorim, 2015) there is, therefore, the need for an environmental urban management appropriate to its different characteristics of land use and occupation and that is able to support local public policies with regard to these varieties, because, being done properly, it has the ability to not only eradicate conflicts, but also distribute benefits equitably, overcoming the externalities of unsustainable development (Vasconcellos, 2001).

The method commonly used to perform the diagnosis, monitoring and subsequent management of urban occupation is the analysis of the distribution and variation of urban land coverage, so that one can have the greatest knowledge about occupations and relate them to political decisions, regulatory actions, and land use (Lemos, Becegato, Becegato, & Rosini, 2021). However, it is common to use Remote Sensing (SR) and GIS techniques, associated with conventional methods of analysis, as important tools to perform effective urban management (De Barros & Lombardo, 2013).

It is in this context, involving the dynamics of cities, that population expansions, especially those that occur in a disorderly manner, stand out for their ability to cause local environmental and climatic changes, causing an anthropic environment and specific climate, which science has named an urban climate (Monteiro, 1976). Such situation is explained by the fact that in urban areas there is an accumulation of energy from the solar incidence and atmospheric radiation balance. Thus, heat is emitted and reflected from urban surfaces, which, in most cases, are composed by materials little evaporative and with lower reflectance capacity (Gartland, 2010; Monteiro, 1976).

In this regard, Santamouris (2011) states that the heat island phenomenon is even more intense in poorly planned cities, being evident to Silva, David, and Bianchi (2017) the need to develop studies that treat the urban climate, especially those that are able to subsidize urban management and managers' decision-making, since the accelerated and disorderly growth of cities is characterized as the main responsible for socio-environmental problems related to the behavior of the urban climate.

According to Rashid, Alam, Chowdhury, and Islam (2022), this urban development has a significant influence on the variation of LST. In addition, the authors point out that green cover could weaken the effect on urban temperature. At this point, it should be mentioned that the exposed environment becomes even more critical when, in the vicinity of these sites, there is open pit mining activity, because, considering the anthropic activities that causes the most negative impacts on the environment, the extraction of ores stands out (Sanchez, 2013), which leads to negative environmental impacts and geological changes reflected on the surface (Millán, Teuwsen, & Pakzad, 2013), these being observed from satellites images (Padmanaban, Bhowmik, & Cabral, 2017).

Li, Li, Song, and Wu (2022) mention that the variation of the superficial temperature and its temporal space variation has become an important management tool to identify surface disturbances. According to the authors, as the mining areas have dispersed ore characteristics and alter the use and occupation of the area, it is of great value to obtain LST data with practicality and high spatial resolution for sustainable environmental management and monitoring.

In this regard, Chatterjee and Gupta (2022) verified that urbanization, related to mining activity, were responsible for altering the surface and microclimatic temperature of the mining industrial region in West Bengal, India, with a correlation between changes in surface temperature and land use and coverage. Dey, Salui, and Biswas (2022) verified, through Landsat-4, 5 and 8, a positive correlation between the spatial distribution of LST and open pit mining activity. The authors also concluded that the activity was one of the main contributors to the precarious state of environmental quality of the adjacent area. Finally, Ogunro and Owolabi (2022) verified, in their spatial-temporal analysis, that the mean values of LST in a mining area in Nigeria showed a constant increase pattern from 23.98°C in 1984 to 29.46°C in 2020, due to, among other aspects, vegetation suppression.

Given the tools used to carry out management studies involving territorial dimensions, geotechnologies have shown a notorious growth in the volume of data produced, because their application in the management of the territory allows defining the sectors of an area that have certain environmental characteristics, as well as their peculiarities (Korchagin, Caner, & Bortoluzzi, 2019). Thus, it is possible to propose the appropriate use, preservation, recovery, or rehabilitation of areas that are degraded by activities that are incompatible with their vocation of use.

Assuming that soil transformation monitoring is essential to control anthropic activities that can cause environmental degradation (Halder et al., 2022), as well as urban heat islands are considered as one of the greatest confrontations of urban life in the 21st century and with direct consequences on health and human performance (Monteiro, 1976), this article approaches the municipality of Paracatu, Minas Gerais State, Brazil, an area chosen to address this study and whose objective is to analyze, between 1990 and 2019, the variations of the LST of its urban network and the open pit mining activity.

As a justification for this, the study by Bidone et al. (2018) stands out. According to the author, due to urban expansion and the growth of mining activity, currently, the distance between the areas is approximately 200 meters, resulting in a series of conflicting and heterogeneous social relations, whose focus is the environment and territory.

Beyond that, there is a need to offer studies that can support the monitoring and territorial management of the municipality, because, so far, nothing is known about the role that the growth of the urban network, as well as the area of mineral expansion, have affected in surface temperature. Therefore, one of the ways to analyze these changes is through SR data, which has become a popular technique due to the great availability of data by orbital satellite images and the reduced cost (Pereira, Biudes, Mota, & De Musis, 2022). Furthermore, it presents itself as a reliable, inexpensive, and practical methodology to subsidize public policies and decision-making actions regarding climate and urban environmental management (Nascimento, Santos, & Jaques, 2022).

Material and methods

Characterization of the study area and choice of the satellite used

Paracatu (Figure 1) is the only historical city in the northwest of the mesoregion of Minas Gerais State, Brazil. The historic center of the city is practically intact, where there are 230 properties that make up the patrimony protected by the National Institute of Historical and Artistic Heritage (IPHAN) (IPHAN, 2012). The municipality stands out for its mineral wealth, which resulted in its creation in 1744 (Pimentel, 2020). According to the latest estimative of the Brazilian Institute of Geography and Statistics (IBGE), Paracatu has a current population of approximately 92,000 inhabitants (IBGE, 2021).

The altitude of the municipality is between 500 and 950 meters, and is part of the São Francisco and Paraná Basins, being the Paracatu River the most prominent one, integral part of the São Francisco. The fauna and flora of the municipality are typical of the cerrado. Its climate is the tropical humid savannah, with dry winter and rainy summer, type Aw, according to Köppen’s classification. The average annual temperature is 22.6°C, with a monthly average of 18°C in the coldest season and 29.1°C in the hottest one. The average annual rainfall is 1,450 mm, with monthly averages below 60 mm in the driest months (Brasil, 1992; Leite & Oliveira, 2015).

Kinross Gold Corporation, one of the mining companies located in the municipality, operates in the activities of mineral research and development, mining, processing and gold commercialization. It is one of the largest gold producers in Brazil, accounting for 22% of the national production (Kinross, 2020).

Regarding the exploration of gold (Au) in the municipality, it was initially carried out by the company Rio Paracatu Mineração (RPM), when studies conducted in the 1980s detected the cubage of a low gold deposit at the site called Morro do Ouro (name of the place where the mineral exploration is located), right on the edge of the city's urban area (Andrade, Alcântara, & Paiva, 2019). For this reason, and to verify changes on the area of mineral exploration from a period just before its beginning, the TM and OLI sensors of the Landsat satellite were chosen for analysis of the chosen series, therefore, making it unfeasible to use other sensors, such as the Moderate Resolution Imaging Spectroradiometer (MODIS).

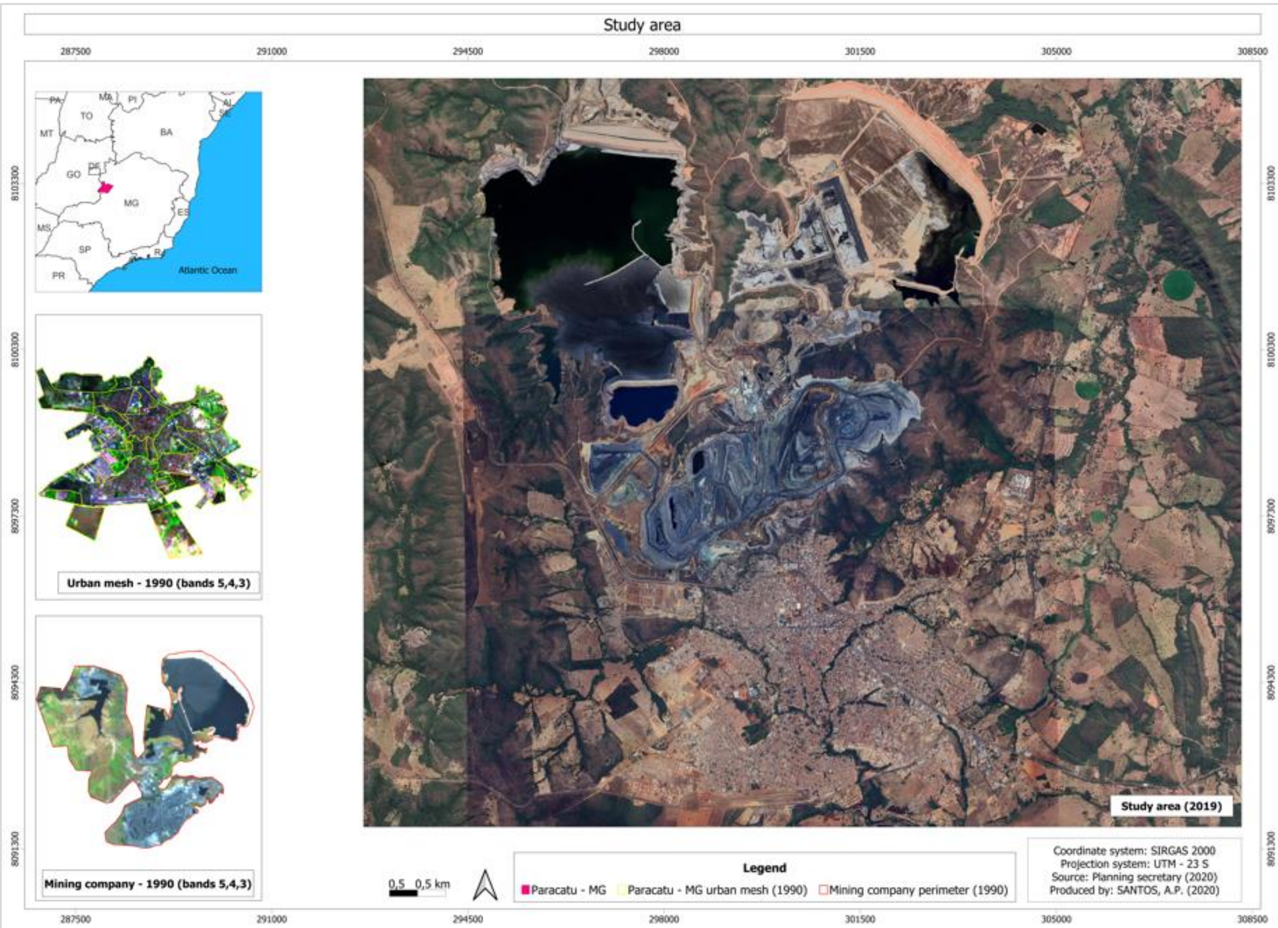


Figure 1. Study area.

Furthermore, the spatial resolution was also considered for this choice. According to Souza and Ferreira (2012), the resolution of landsat series sensors allows identifying thermal features related to areas such as parks and green areas, which also present mild temperatures in the urban network. Therefore, it is possible to carry out studies focused on the evaluation of the thermal dynamics, as well as on the evaluation of the contribution to the thermal amenity in urban areas.

Data gathering

At this stage, it is worth mentioning that studies involving SR data and time variations of LST are increasing and generally use a certain number of images to represent a respective season and even a whole year, according to related studies (Wang et al., 2018; Bezerra, Moraes, & Soares, 2018; Abdolalizadeh, Ebrahimi, & Mostafazadeh, 2019; Carrasco, 2020).

However, this study chose to analyze the years (Table 1) in which El Niño and La Niña phenomena did not occur, as these may have significant effects on surface temperature variation (Reis, Silva, Klering, Lindemann, & Maier, 2022), and also in biomass production (Junges & Fontana, 2015; Kemarau & Eboy 2022). Data from LANDSAT-5 and LANDSAT-8 satellites were obtained from the United States Geological Survey (USGS) website and then standardized for the same reference system: SIRGAS 2000 in UTM Timezone 23S. For each year of the analyzed series, 2 images were used, and the average of the images chosen for the year were performed. Therefore the 10 satellite images used resulted in 5 images for the final layout, 1 for each year.

Regarding the presence of cloud, images were used in which there was no presence of these covering the area of study, as recommended by Carrasco et al. (2020). Finally, 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 pixels from different satellites used (100 meters).

Table 1. Years and dates of the images chosen for analysis.

Year	Image 1	Image 2
1990	06/05/1990	05/20/1990
1995	06/03/1995	05/18/1995
2005	04/11/2005	05/13/2005
2014	06/04/2014	05/22/2014
2019	05/02/2019	06/21/2019

Source: https://earthexplorer.usgs.gov/

At this point, it is worth to point out the influence of the presence/scarcity of water for LST analysis, because the moisture of the material tends to alter the albedo, which represents the part of the solar radiation that is reflected by a material, and, as a result, greater/lower is its ability to absorb and reemit energy later, also increasing the tendency of temperature elevation/decrease. In addition, greater neutrality of soil water availability is associated with neutral years, and greater availability to El Niño events (Sohoulande Djebou, Singh, & Frauenfeld, 2015; Amorim, 2017).

Subsequently, a season to be worked on was chosen, which is the autumn season. This season was chosen for 2 reasons: i) due to the low incidence of clouds, which ensures better visibility of the surface and greater attenuation of atmospheric effects; and ii) because it is a transition period between summer (humid period in the region and with possible water surplus in the soil) and winter (dry period in the municipality and with possible water stress in the soil) (INMET, 2020). A comparative study between LST and official data from meteorological stations show up to 86.2% accuracy between the spring and summer seasons. However, for periods between autumn and winter, results vary, with up to 93.1% accuracy. Furthermore, in spring-summer periods, LST presents a large thermal amplitude, while between autumn and winter, it is more distributed (Nascimento et al., 2022).

To meet the objective of the study, the research was divided into two phases, being: i) the mapping and processing of LST in these areas; and ii) analysis of the difference between the minimum, mean and maximum LST values across the years.

For the multitemporal analysis and construction of LST maps, the LANDSAT-5 satellite band 6 and the LANDSAT-8 satellite band 10 were used, which correspond to their respective thermal ranges in the electromagnetic spectrum, and the vector files on format shapefile, which represent the country, state, municipality, and area of interest of the research. The vector files used were: i) limit of the territory of Brazil; ii) limit of the state of Minas Gerais; iii) boundary of the municipality of Paracatu; iv) boundary of the area of open pit gold mining; and v) urban mesh.

The items (i), (ii), and (iii) are available free of charge on the platform of the Brazilian Institute of Geography and Statistics (IBGE) and on the scale 1:250,000 (IBGE, 2020). Regarding the elaboration of the shape of mining activity (iv) and (v), this was produced through the combination RGB (5, 4, 3) in the image of the year 2019, taking into consideration their respective locations through the Open-source Software Google Earth Pro and validated with prior knowledge of the municipality. In relation to the shape of the urban mesh (vi), this was obtained from the Secretariat of Planning of the municipality of Paracatu with a scale of 1:50,000. It should be mentioned that the file made available by the municipal secretariat contained, in its table of attributes, numbers for each neighborhood. As these are used for municipal management purposes, there was no change made on the attributes.

Extraction of LST from satellite images

To calculate the LST of the areas under study, the software QGis 3.2.12 (QGIS, 2021) was used in each image obtained and to be analyzed. Subsequently, the average was performed between the two images in Table 1. For the landsat-8 satellite, the value of -0.29 was added for each pixel of the image resulted from the mean, according to the recommendation of (USGS, 2016), because the 10 and 11 thermal bands receive scattered light interference from areas adjacent to the imaged scene and therefore require such adjustment.

Afterwards, in each year analyzed, the shape of the urban mesh and the mining area of the last year of the time scale was applied, which represents the current situation of the study area. Finally, the maps containing the LST of each place of interest were elaborated. Regarding the elaboration of the layout, these images were separated into classes, and their values were expressed in degrees Celsius (°C): <16; 16.1 to 18; 18.1 to 20; 20.1 to 22; 22.1 to 24; 24.1 to 26; and >26.1. The values were classified by the standard deviation technique.

Extraction of shape pixel values and data analysis

Regarding the extraction of the pixel values of the shapes used, the ENVI software was used in version 5.2. First, the image representing the year was exported from Qgis to ENVI after the application of the method used. Once completed, the shape elaborated in Qgis was applied in the image and the pixels conversion into the shape using the Region of Interest (ROI) plug-in available in the software was performed. With the LST values of all shapes and all years of the series, they were statistically analyzed

It is worth mentioning that, at this point, the validation of the data obtained was performed, based on the first and last year of the analyzed series, by means of Atmospheric Temperature (AT) measured in a conventional station of the National Institute of Meteorology (INMET) (code 83479; altitude 711.41 m; latitude: -17.244166 and longitude: -46.881666), accessed from its official website.

Analysis of the neighborhoods that most and least varied in their LST

At this point, all the features that represents the neighborhoods of the municipality were selected, creating a .shp file for each one. Subsequently, these were exported to the ENVI software and, in ROI, each neighborhood was selected. In order to verify the neighborhood that varied the most/least in its LST, the variation between the means obtained was performed for each year.

Analysis of the NDVI

In order to verify a possible cause of the largest and smallest variation between the analyzed neighborhoods, the images were corrected to the effect of the atmosphere and, afterwards, the NDVI was applied in the first and last images of the analyzed series, according to Rouse, Haas, Schell, and Deering (1975).

Results and discussion

Through the methodological application described, the values corresponding to the LSTs for each year of the analyzed series were obtained. Figure 2 illustrates the results obtained for the urban mesh, and Figure 3 for the open pit mining area. Figures 4 and 5 show the mean, minimum and maximum variation of LST in each year analyzed in the respective study areas. In Figure 6 is presented the spectral response presented by the NDVI index.

It was verified, through the result of the multitemporal analysis of LST, in relation to the urban mesh, that it presented a variation of more than 4°C in the means analyzed, between the first and last year of analysis. This was also observed in the maximum (3.9°C) and minimum (4.4°C) values between these years. This situation is related to the process of high urbanization of the municipality, which is one of its main characteristics (Rezende & Marques, 2017).

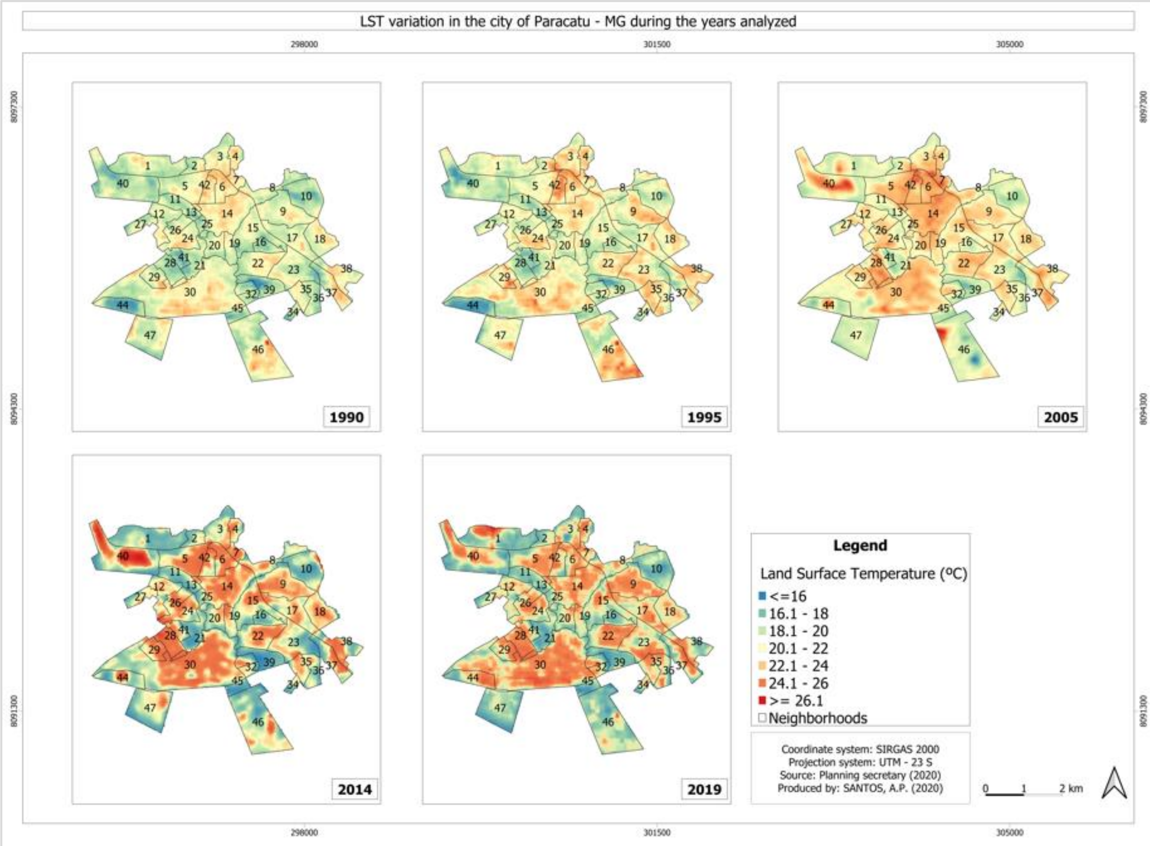


Figure 2. LST variation in the city of Paracatu, Minas Gerais State, Brazil, during the years analyzed.
Source: Authors (2021).

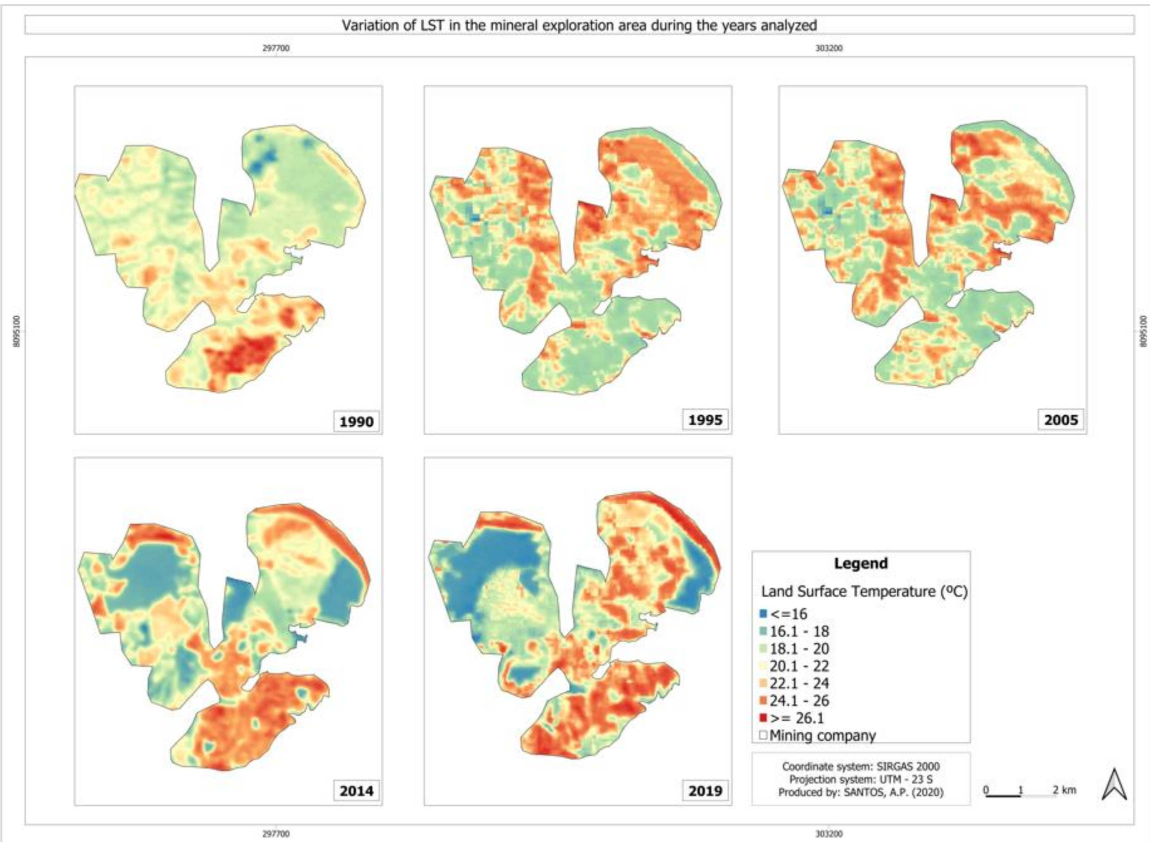


Figure 3. Variation of LST in the mineral exploration area during the years analyzed.
Source: Authors (2021).

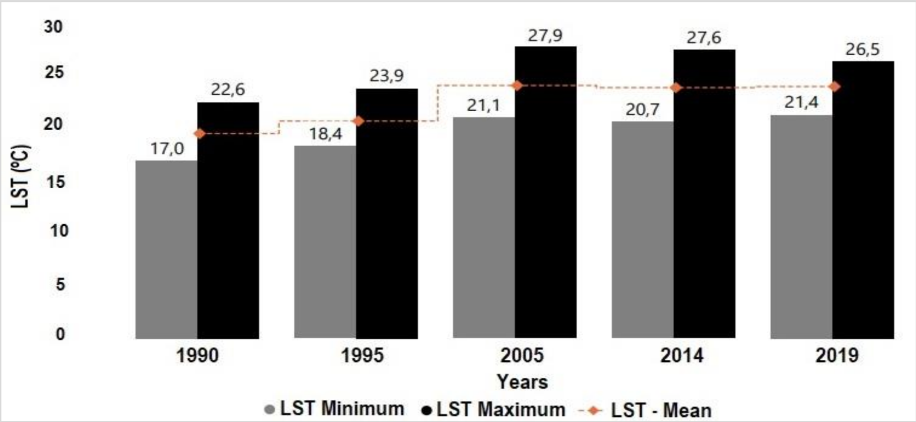


Figure 4. Minimum, average, and maximum variation of LST in the urban mesh area during the years analyzed.
Source: Authors (2021).

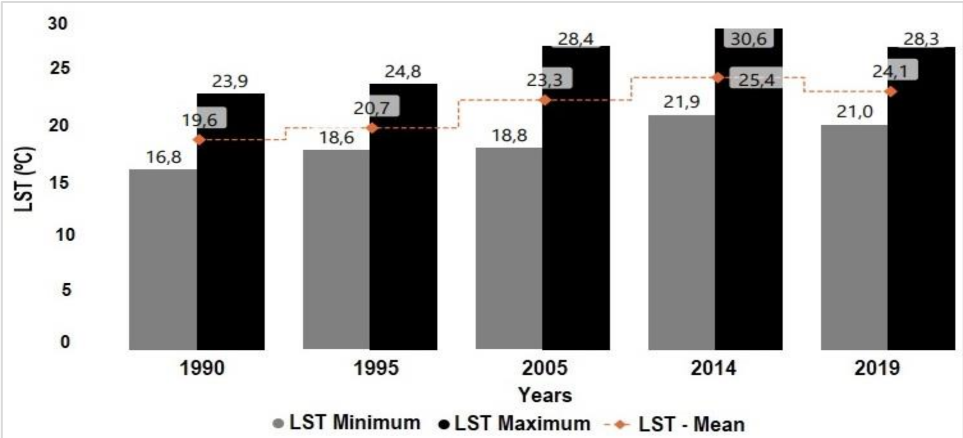


Figure 5. Minimum, average, and maximum variation of LST in open pit mining during the years analyzed.
Source: The authors (2021).

During the first and last year of the analyzed series, the urbanization rate increased by more than 20%. It is worth mentioning that, from the time the urbanization process occurs, it results in a decrease in vegetation and, consequently, an increase in surface temperature, according to related studies (Souto & Cohen, 2021; Moisa, Merga, & Gemeda, 2022).

Furthermore, the results show that urbanization in Paracatu most likely presented local and regional climate change, because, as presented by Abdullah, Abdullah, and Rabby (2022), urban growth has a significant impact on the microclimate as it introduces several environmental issues, including changes in LST. In this context, Kaiser et al. (2022) used satellite images, on a 34 years range, to verify the difference that the removal of vegetation cover in the urban center of Porto Alegre (Rio Grande do Sul State, Brazil) caused in the average increase in LST (4.18ºC).

Regarding the variation of the LST of the open mineral extraction area, this area presented, when analyzing the first and last year of the analyzed series, variation of approximately 4ºC on its maximum. In relation to the mean value presented, this varied more than 3ºC. In relation to the minimum, there was a variation of more than 4ºC. This fact may be associated with the negative impact caused by the gold extraction and the constant movement of land, as mentioned by (Millán et al., 2013). Moreover, this situation may also be related to the bare soil found in this area, without any type of vegetation cover, because, according to Carrasco et al. (2020), land use and land cover influences directly on the variation of LST.

Given the scenario of mineral and urban expansion, it is important to highlight those changes in vegetation cover modify energy distribution patterns, strongly impacting important variables such as LST (Pereira et al., 2022). In addition, the open pit mining process leads to large-scale vegetation degradation, causing land desertification and differentiation of surface temperature (Li et al., 2022). In cities, to accommodate their population growth, the urban environment needs to be constantly changed, with the respective decrease in the green area and expansion of streets and buildings, causing an increase in the variation of LST, which is found more in less vegetated areas (Hasim, Al Maliki, Sultan, Shahid, & Yaseen, 2022).

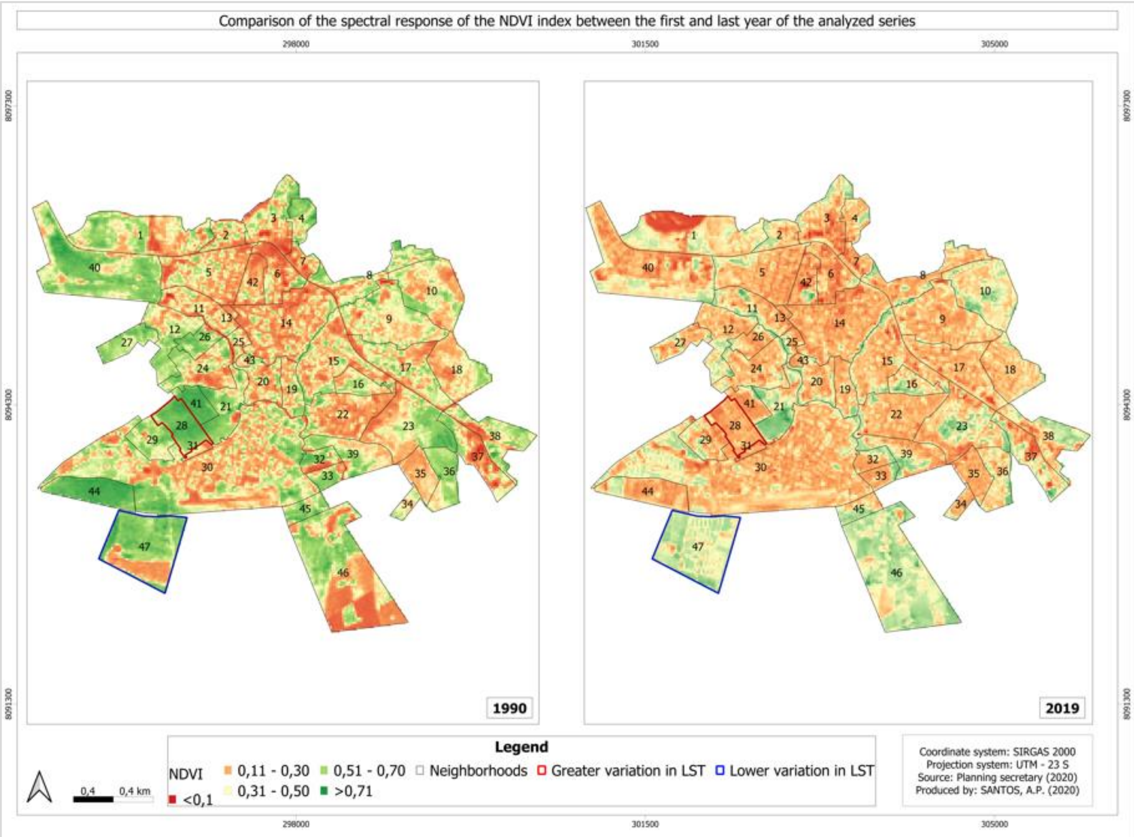


Figure 6. Comparison of the spectral response of the NDVI index between the first and last year of the analyzed series.
Source: The authors (2021).

In this context and according to Sousa and Ferreira (2012), one of the negative environmental impacts that can be considered in the process of conversion of use and occupation is the change in the thermal field through the substitution of natural surface coverings and the appropriation of these spaces for anthropic activities (Alves, 2017; Amorim, 2019; Moreira & Amorim, 2015).

Through the difference between the means of the neighborhoods of the municipality of Paracatu, it was possible to verify that the neighborhood that varied the most, in relation to its mean, in its LST, was the neighborhood 22 (6.30). Neighborhood 47, on the other hand, presented the lowest variation (3.30). This reduction is related to the increase of built areas and, consequently, suppression of vegetation, considering that this degradation is noticeable in spectral responses between the years analyzed.

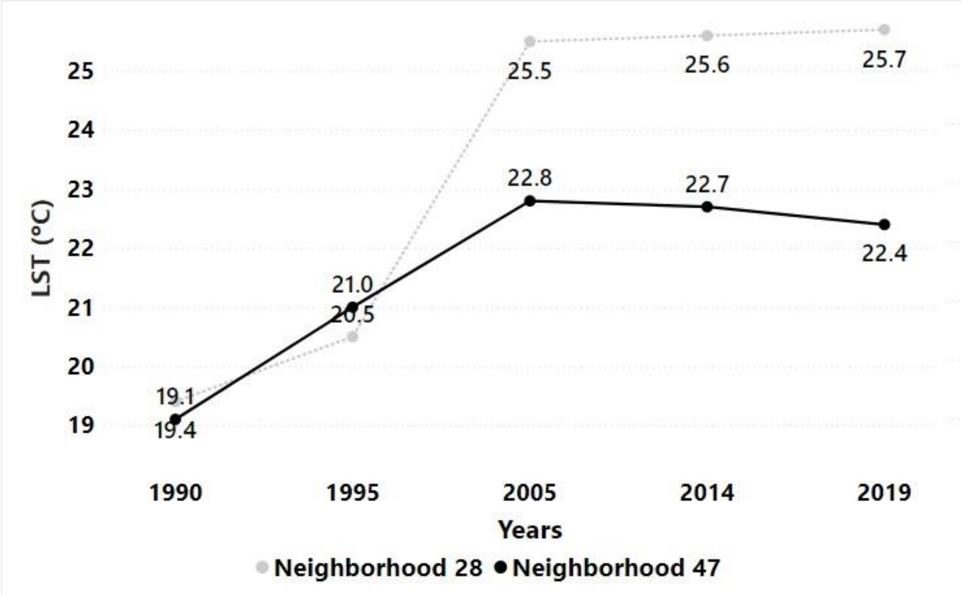
Figure 6 shows the result of the application of the NDVI in the urban network of the municipality of Paracatu, Minas Gerais State, Brazil. According to Millán et al. (2013), the NDVI has a good correlation with biomass and, consequently, has a relationship with the LST of the area. According to Abreu and Labaki (2010), the physiological process of evapotranspiration of trees is responsible for conditioning the temperature and relative humidity of the air in its surroundings, thus providing better thermal sensations to the local environment, which is called thermoregulation. The behavior of the mean, minimum and maximum LST in these neighborhoods, is shown in Figure 7 and data validation in Table 2.

Table 2. Validation of LST data.

	1990		2019	
Descriptive statistics	LST	AT	LST	AT
Minimum (°C)	17.0	13.7	21.4	20.2
Maximum (°C)	22.6	27.0	26.5	28.5
Mean (°C)	19.6	20.2	24.1	23.83

Source: The authors (2021).

It is important to note that in 2005, the urban mesh presented a peak on its mean, minimum and maximum surface temperature. This can be explained by the fact that this year was the only one, of the analyzed series, in which a satellite image of the month of April was used (different from the whole series). However, for the purposes of multitemporal analysis, we chose to use image of the referring month and use the year 2005 in the analysis, because, otherwise, there would be an interval of almost 20 years between the 2nd and 3rd year analyzed.



Source: The authors (2021).

Figure 7. LST Variation in the neighborhoods that varied the most and least during the fall in the series analyzed.

In relation to the multitemporal variation of the NDVI, it was possible to observe the vegetation reduction during the expansion of the area occupied by neighborhood 28 and, partially, by neighborhood 47. This reduction is possibly related to the increase of constructed areas and, consequently, suppression of vegetation, considering that vegetation degradation is perceptible when comparing the analyzed years. According to Yue et al. (2007), urban meshes have a heterogeneous scenario, in which green areas have high NDVI values and built urban, or central areas, with low NDVI values and low vegetation index. The authors also point out that the spatial distribution of NDVI in urban heterogeneity, with different uses and land cover, presents values opposed to LST.

It should be noted, at this point, that neighborhood 47 is considered a neighborhood, currently, because an allotment is being built on site. According to information collected in the city hall, in 2019 (last year analyzed), the suppression of vegetation for construction was occurring in some lots of the neighborhood, which is visually explained by the behavior of the NDVI. This situation highlights the importance of studies covering the behavior of LST and NDVI for urban planning purposes, because, according to Wilson, Clay, Martin, Stuckey, and Vedder-Risch (2003), vegetation cover in parks or other type of green terrain, as is the case of neighborhood 47, suggests comparatively higher rates of evapotranspiration, favoring the exchange of latent heat between the surface and the atmosphere, when compared to places with less vegetation.

The results presented in this research also allow the identification of areas with higher and lower temperature, contributing to a faster decision making in peculiar sectors of the city, besides enabling the creation of green areas in strategical points of the municipality, in order to reduce the possible formation of heat islands.

Through the results obtained it is possible to verify that, currently, the municipality of Paracatu needs points - here called strategical - to be replanned environmentally. Neighborhood 20 is one of the examples of this situation. Located in the peripheral area of Paracatu, it is considered the largest neighborhood, in population and extension, of the municipality. It is possible to notice that its LST has always been, when compared to the other neighborhoods of the municipality, considered high, as well as the lack of vegetation. Because it is a neighborhood that, for many decades, was considered attractive to the low-income population, its use and occupation was most likely not planned, which urgently entails the need of mitigating measures to control the situation.

Rezende & Rosa (2016) found that the recent sectors of urban occupation, in Paracatu, have no vegetation on sidewalks, which should not occur, because the Municipal Complementary Law 063 of 2009 attributes the obligation of planting trees in public sidewalks, respecting pedestrian traffic, in new buildings. In addition to it, the planting and conservation are the responsibility of the landowner. Therefore, it was noticed that, as much as public management plays its role in demanding the planting of trees on sidewalks, this is not strictly fulfilled by the residents, who plant them only to get the approval for property usage but are not keeping it later on.

In relation to neighborhood 38, considered as the central neighborhood of the municipality of Paracatu, presented a scenario of exponential growth of LST. This situation may be related to the high urban growth that the municipality presented until 2010. Subsequently, this neighborhood presented a decrease in the mean values of LST, which may be related to the beginning of the replanning and concern, on the part of public managers, regarding the afforestation of the central area of the municipality.

The neighborhoods such as neighborhood 44 and 42, located in a peripheral area more distant from the municipality, have never had a high peak of their LST, which may be related to the geographical distance between these neighborhoods and the municipal center. It is worth noting that, currently, the municipality does not have many services (banks, hospitals, pharmacies, schools, supermarkets, sports centers and leisure areas) outside its central region, which ends up driving residents away from the most distant neighborhoods. It is emphasized that the peripheral areas located on the opposite side of these neighborhoods (neighborhoods 11, 10, 14, 9), are neighborhoods closer to the municipal center, which may have influenced the choice of the population to prioritize the occupation of this area. According to information collected on the site of the municipality, in 2019, in order, among other factors, to relieve the urban center of the city, leaving all the services of municipal departments - until then, scattered throughout the urban center - the public management began to shift all services of the city to an administrative center located in a peripheral area of the municipality.

Finally, it is emphasized that the municipality has already been used as a case study involving the application of urban climate data for the development of master plans. According to the authors, the city has very low speed records in relation to the wind. Considering the occurrence of high temperature and humidity in a given period of the year, good ventilation conditions are required to maintain air quality and to reduce the effects of the formation of the urban heat island. Furthermore, the study showed a strong influence of topography and local occupation on wind direction, as low wind speeds (0.1 m/s) were presented in areas where the densest urban occupation is. Additionally, it was observed that the relatively warmer area, in the urban center, presented values with low wind speeds (Assis, Ramos, Souza, & Cornacchia, 2007).

Conclusion

It was possible to identify differences of spatial and temporal patterns in vegetation cover, and surface temperature, in relation to the anthropic activities in the study area, which confirms the need to have an appropriate urban and environmental planning for the site that are able to regulate the growth of urbanization and the area of open pit mining activities. Regarding the urban mesh of Paracatu, the analysis between the vegetation cover data, from the use of NDVI, and the surface temperature data indicates that the use and occupation in the municipality occurred in a disorderly manner, therefore, the maps generated in this study can be used as a subsidy to identify vulnerable sectors to the heat island processes, and are strategical in the expansion context. Finally, it was possible to conclude that the spectral changes that occurred between the images of the years analyzed, in both anthropic activities, are related to their disturbed growth, and there is a need for measures able to mitigate the negative impacts of those.

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