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The Use of NDVI and NDBI to Provide Subsidies to Public Manager's Decision Making on Maintaining the Thermal Comfort in Urban Areas

Arthur Santos, Fernando Santil and Claudionor Silva

Abstract

The use of physical indexes such as NDVI (Normalized Difference Vegetation Index) and NDBI (Normalized Difference Built-up Index), related to the variation of Surface Temperature (LST), have been widely used as support for mapping and monitoring land use and occupation, mainly in urban centers, due to, among other factors, changes in the energy balance and, consequently, increase heat of cities. Thus, this study approaches the urban space of the municipality of Paracatu, Minas Gerais (MG) and aims to verify urban growth, through the variation of NDVI, NDBI and LST, between the years 1990 and 2019 by using images of the LANDSAT-5 and LANDSAT-8 satellites. As a final result, an urbanization map of the municipality was obtained, and it was possible to verify that these indexes were adequate to size the environmental impact caused by disordered urbanization, since the degradation of vegetation caused in the area was responsible for reducing and/or increasing the values recorded by the indexes. In addition, the results made it possible to identify areas with higher and lower temperature variations, causing the agility of decision-making and the development of projects that meet the peculiarities of each sector of the city.

Keywords: NDVI, NDBI, LST, urban growth, spectral indexes

1. Introduction

There is an increasing trend, by public and private administrations, on seeking a renewal on the way in which the data representing its territorial aspects are managed. This change is mainly due to the strong need for basic, and reliable, information to be used as base of decision-making for society.

Thus, and given its ability to observe the earth's surface at local, regional and global scales, Remote Sensing [SR] presents itself as an important tool to perform monitoring effectively, in addition to improving the systems already available therefore support managers in their decisions [1]. Moreover, because they are obtained, on most occasions, free of charge, these data have been used for science, education

and technology purposes in many countries, which are fundamental resources to identify problems, visualize panoramas and propose viable political alternatives in territorial management [2].

It should be noted that, regarding the anthropic activities that cause negative environmental impacts and that require monitoring, the growth of urban centers in a disorderly manner, especially in developing countries, has been causing gradual changes in land use and cover [3] due to the change in vegetation by materials that have the capacity to store heat [4, 5] and, as a result, increase the thermal temperature of urbanized areas and causes changes in the local, regional microclimate and in the well-being of the population through thermal discomfort, according to related studies [3, 6].

Historically, urbanization, begun around 1950, initiated changes in natural landscapes. The disorderly growth of large cities and their growing interference in the environment has made them, and keep on making them, increasingly less sustainable [7]. Therefore, what has been happening in these areas, is the emergence of a specific climate on the site, which is related to the impact of urban development on the surface heat balance [8], causing the formation of the Urban Heat Island (ICU) phenomenon and which can be considered the most evident example of climate change caused by anthropic action [8, 9].

In order to analyze and monitor these variations, the results of research that analyze, through data from SR - spectral indices and variations in Surface Temperature [LST] - is gradual, the impact of these changes on the multiscale landscape, particularly with the use of vegetation indices, due to their ability to detect the presence and absence of vegetative, with emphasis on the Normalized Difference Vegetation Index [NDVI] and also for the Normalized Difference Built-Up Index [NDBI], which assesses the urban development of the built area.

In Brazil, there are few studies that address the impacts of urban expansion in a disorderly manner. As a result, cities grow in disharmony to their ecosystem aspects. In this context, there is the municipality of Paracatu, Minas Gerais (MG), an area of study of the present study and that very little is known, so far, about the impacts caused by its urban expansion. The present work is justified by the fact that, according to the Atlas of Human Development in Brazil [ADHB], in the last decade, the population of Paracatu grew at an average annual rate of 1.20%, while in Brazil, this rate was 1.17% for the same period [10] and aims to analyze, between 1990 and 2019, the urbanization of the municipality of Paracatu through the NDVI and NDBI, as well as its consequences on the well-being of the population.

2. Material and method

2.1 Study area

Located 220 km from the Brazil's capital, Brasília - DF, Paracatu - MG (**Figure 1**) is the only historical city at the northwest of the mesoregion of Minas Gerais. Founded due to its mineral wealth, the municipality is a national reference in the exploration of gold and zinc [11]. According to the latest IBGE estimate, Paracatu has a current population of approximately 94,000 inhabitants [12].

2.2 Data acquisition

Data from LANDSAT-5 and LANDSAT-8 satellites were obtained from the United States Geological Survey (USGS) website. The years in which el niño and

Figure 1.
Study area. Source: Authors (2021).

La Niña phenomena did not occur were analyzed. Subsequently, autumn was chosen in the southern hemisphere as the period of the year to be analyzed.

The choice of this season was for 2 reasons: a) due to the low incidence of clouds, which guarantees the better perceptibility of the surface and the greater attenuation of atmospheric effects and; b) because it is a transitional period between summer and winter [13]. At this point, it is worth noting about the influence of the presence/scarcity of water on LST records, because the moisture of the material tends to alter the albedo, which represents the part of the incident solar radiation that is reflected by the material, and, as a result, greater/lower is its ability to absorb and reemit energy later, also increasing the tendency of temperature elevation/decrease [14–16].

The images of the following years were requested: 1990, 1995, 2005, 2014, 2019 and then cut to the study area. All data were standardized for the same reference system: SIRGAS 2000 in UTM Time Zone 23S. It should be noted that, for each year, 2 images were chosen that could represent the autumn season, being: 05-June-1990; 20-May-1990; 03-June-1995; 18-May-1995; 11-April-2005; 13-May-2005; 04-June-2014; 22-May-2014; 02-May-2019 e; 21-June-2019.

For the multitemporal analysis and production of the urbanization map, we used the 6 band of the LANDSAT-5 satellite and the 10th band of the LANDSAT-8 satellite, which correspond to their respective thermal ranges in the electromagnetic spectrum, and the vector files in shapefile format (.shp), which represent the country, state, municipality and area of interest of the research.

The vector files used were: a) limit of the territory of Brazil; b) limit of the state of Minas Gerais; c) boundary of the municipality of Paracatu - MG; d) urban mesh. It is notable here that items (a), (b), and (c) are available free of charge on the platform of the Brazilian Institute of Geography and Statistics (IBGE) and on the scale 1:250,000 [17]. Regarding the mask of the urban mesh (d), this was obtained from the Planning Secretariat of the municipality of Paracatu and with a scale of 1:50,000.

2.3 LST extraction

For the calculation of the LST of the areas under study, Eq. (1) was applied using the software QGis 3.2.12 [18] in each image obtained.

Eq. 1 - LST calculation.

$$T = \left(\frac{K2}{\ln \left(\left(\frac{K1}{ML * Qcal + AL} \right) + 1 \right)} \right) - 273.15 \tag{1}$$

Source: [19].

Being: ML = Multiplicative factor of resizing the thermal band*, AL = Thermal band-specific additive resizing factor*, Qcal = Quantized value calibrated by pixel in DN, T = temperature in Celsius, K2 = constant of calibration 2* e K1 = constant of calibration 1*.

*Values used in the processing of images and taken from the metadata file.

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 [19], because the 10 and 11 thermal bands receive scattered light interference from areas adjacent to the imaged scene and therefore require this 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 ($^{\circ}\text{C}$): <18 ; 18.1 to 20 ; 20.1 to 22 ; 22.1 to 24 ; 28.1 to 30 . The values were classified by the standard deviation technique.

2.4 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 [20]. 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 was performed the pixels conversion into the shape using the Region Of Interest (ROI) plug-in

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

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

available in the software. With the LST values of all shapes and all years of the series, these 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.

2.5 Analysis of the NDVI, NDBI and mapa de urbanização

In order to verify a possible cause of the largest and smallest variation between the analyzed neighborhoods, the images were corrected of the effect of the atmosphere and, later, the NDVI (Eq. (2)) was applied in the first and last images of the analyzed series.

Eq. 2 - NDVI calculation.

$$NDVI = \frac{(NIR \rho_{(830\mu m)} - RED \rho_{(660\mu m)})}{(NIR \rho_{(830\mu m)} + RED \rho_{(660\mu m)})} \quad (2)$$

Source: [21].

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

For the calculation of NDBI, the Near Infrared ($0.76-0.90 \mu m$) and Mid-Infrared ($1.55-1.75 \mu m$) bands were used. Due to the fact that the NDBI is based on the fact that constructed lands have a higher infrared reflectance of medium waves than in shortwave infrared, it is expected, with this index (Eq. (2)), that it presents higher values in more densely urbanized areas.

Eq. 3 - NDBI calculation.

$$NDBI = \frac{(NIR \rho_{(0,76-0,90\mu m)} - MID-IR \rho_{(1,55-1,75\mu m)})}{(NIR \rho_{(0,76-0,90\mu m)} + MID-IR \rho_{(1,55-1,75\mu m)})} \quad (3)$$

Source: [22].

Where: NIR corresponds to the near infrared band and MID-R corresponds to the band located in medium infrared.

In order to verify the effect of urbanization between the first and last year of analysis, the mean LST was performed among the 10 images analyzed in the last 29 years.

3. Results

Regarding the variation in spectral indices, between 1990 and 2019, these are arranged, in relation to the NDBI, in **Figure 2** and, in relation to the NDVI, in **Figure 3**.

Regarding the urbanization of the study area, between 1990 and 2019, this is shown in **Figure 4**.

Figure 2.
Variation of the NDBI in the urban mesh of Paracatu - MG. Source: Authors (2021).

Figure 3.
Variation of NDVI in the urban mesh of Paracatu - MG. Source: Authors (2021).

4. Discussion

In relation to the multitemporal variation of spectral indices, it was possible to observe the reduction, practically total, of vegetation during expansion in some

Figure 4.
Map of urbanization of the municipality of Paracatu - MG. Source: Authors (2021).

parts of the urban mesh of the municipality, especially in its central region. This reduction is possibly related to the increase in constructed areas, as presented by the NDBI and, consequently, suppression of vegetation, considering that vegetation degradation is noticeable in the visual comparison between the years analyzed.

It is worth mentioning that, according to [23, 24], urban meshes have a scenario in which urban areas built, or central, have low NDVI values and low vegetation. 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.

Through the results obtained it is possible to verify that, currently, the municipality of Paracatu needs to have some areas - 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 its population and extension, of the municipality, a fact evidenced by the change in NDVI and NDBI over the years and also with the urbanization of the neighborhood in this period.

In relation to neighborhood 38, considered as the center of the municipality of Paracatu, it presented a scenario of growth in the variation of spectral indices. This situation may be related to the high urban growth that the municipality presented until 2010.

Finally, it is worth noting that some neighborhoods located in a peripheral area, distant from the central region, have never had a high peak of urbanization, which may be related to the geographical distance between these neighborhoods and the city center. 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 these most distant neighborhoods.

Finally, it is important to point out that some neighborhoods, that are closer to the municipal center, presented variation in spectral indices and also high values of urbanization, a fact that may be related to the choice of the population to prioritize the occupation of this zone closer to the central region. It should be noted that, in

2019, the public management of the municipality began to move all the services of the city to an administrative center located in a peripheral area of the municipality to, among other factors, relieve the concentration of vehicles and services at just one area of the municipality.

5. Conclusions

Considering the results obtained, it was possible to conclude that NDVI and NDBI, tied to LST data, is adequate to size the environmental impact caused by urbanization in a multitemporal way, since the degradation of vegetation caused in these areas is responsible for reducing and/or increasing the values recorded by the indexes.

The results reinforce the importance of environmental parks and urban afforestation, not only as landscaping, that is as a mere architectural element, but as an element of maintenance of thermal comfort in the urban space, especially in the area of study, being possible, in this way, to modify the microclimate and bring several benefits to the well-being of the population, as it contributes to the quality of life and health.

The results presented in this research also allow the identification of areas with greater and lower temperature variations, causing the agility on the decision-making process and the development of projects that meet the peculiarities of each sector of the city, thus enabling the creation of green areas in strategic points of the municipality, in order to, among other factors, reduce the possible formation of heat islands.

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