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Spatial-time variation by Built-up and NDBI indices of the municipalities of Maringá and Sarandi/PR: comparison between the years 2013 – 2020

Diogo Yukio Uema
Doctoral student in Geography; specialized in Geoprocessing, UEM, Brasil.
contato.diogoyukio@gmail.com

Renan Valério Eduvirgem
Doctoral student in Geography; specialized in Archaeology, UEM, Brasil.
georenanvalerio@gmai.com

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SUMMARY

This work aims to use the Normalized Difference Built-up Land Index and Built-up Index to evaluate the urban perimeters of Maringá and Sarandi, Paraná. In order to identify if there was a spatial difference in the built areas. The methodological procedures were based on the spatial analysis of urban perimeters, generation of each index, interaction between index and environment. In the results and discussions, the values obtained by the indexes are approached and the localities with higher and lower values are scored, with possible causes denoted, as well as the relationship with the literature. It was concluded that Maringá and Sarandi, Paraná, have urban density in an advanced stage of urban consolidation, in the perspective of soil waterproofing, since the indexes worked do not measure vertical densities, but horizontal ones.

KEY WORDS: Vegetation Index. Soil waterproofing. Building area.

1 INTRODUCTION

The growth of urban population in the world becomes more and more evident, as the urban agglomerations expand and intensify. The estimate for the middle of the 21st century is that more than 67% of the world's population inhabits the urban environment (UNITED NATIONS, 2018).

In Brazil, in 2010 (when the latest population census took place), the urban population corresponded to more than 80% in relation to the absolute population (IBGE, 2010). This growth can promote an increase in the areas of conurbation, making the evaluation of these areas favorable.

Assessing the growth of areas built in the urban environment is essential to understand the temporal evolution, which enables the results to be used for management and decision making, thus generating the possibility of inserting implements that promote environmental sustainability, for example.

One of the indices that allow to evaluate the increase of urban constructions is the Normalized Difference Built-up Index (NDBI). This index presents spectral sensitivity in the urban environment, and may present different values (SEKERTEKIN; MARANGOZ, 2017).

The NDBI was developed by Zha, Gao and Ni (2003). The ability to map built areas with an accuracy level of 92.6% was emphasized, although the authors pointed out that this index has a higher quality than the supervised classification.

Sekertekin and Marangoz (2017) used scenes from the Landsat 8 satellite to test indexes that measure the built environment. The authors denoted a good result for the images of this satellite, and the excellent result of the NDBI was notorious.

Bacic (2018) used the NDBI as a tool to promote the expansion of the built areas of the highways that intercept the Mario Covas Ring Road (SP-21) analysis. In the study, the author points out that the built areas can be confused with bare land, thus, with the researcher having to use the NDBI, for the responsibility of promoting this differentiation of the spectral signature.

While on this subject, Souza and Ferreira Júnior (2012) also identified similar values for constructed areas and rural areas. For this reason, the authors stated that the NDBI is not effective when it is compared to urban and rural constructions.

In this perspective, it is evident that the NDBI is an important building construction index, however, it is effective in the analysis results that consider only the urban perimeter, or even fragments of the urban space. Although, in this spatial cutout, researchers must analyze with caution, considering that in the urban environment there may be plots of land (lots) with bare land.

In a study carried out in Penápolis, São Paulo, by Moreira and Amorim (2016) using the NDBI (with scenes from the Landsat 8 satellite), it was identified that densely built areas, metallic roofs and bare lands, presented positive index values, close to +1.

In contrast to the study carried out in the previous paragraph, Oliveira, Candeias and Tavares Júnior (2019), in an analysis of the international airport of Recife / Guararapes - Gilberto Freire, found a lower value, the maximum being 0.37. Thus, expressing the differentiation of areas built to a greater or lesser extent, and the NDBI was able to promote this differentiation.

Gomes et al. (2018) used the NDBI to analyze the urban expansion process in Parnaíba, Piauí. This index allowed the authors to identify broad growth in the urban network in the 18 years analyzed (2000-2018). The maximum values found were 0.061 (2000) and 0.188 (2018), thus revealing a difference of 67.5% between the two analyzed Landsat scenes.

Using the NDBI, Leite (2018) promoted a 20-year analysis between the municipalities of Teresina (Piauí) and Timon (Maranhão), contemplating a conurbation. Maximum values from 0.28 to 0.42 were identified, in which 0.32 was the mode (of the data set) of the listed time series. Thus, presenting low intensification in construction between 1997 and 2017.

To correct the problem denoted as bare land and other land cover categories, Zha et al. (2003) proposed the Built-up index (BU), allowing to differentiate impermeable and permeable areas. This index was used and successfully approved by the authors He et al. (2010), Sakuno et al. (2017), Martins, Morato and Kawakubo (2018), Rezende and Rosa (2019).

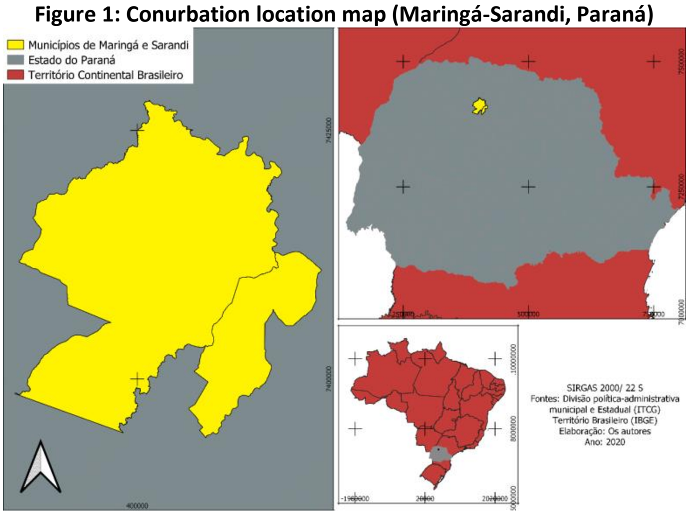
The goal of this paper is to use the NDBI and BU indexes to evaluate the urban perimeters of Maringá and Sarandi, Paraná. Thus, to identify whether there was a spatial difference in the built areas.

2 METHOD OF ANALYSIS

2.1 Location and description of the study area

According to data from the IBGE cities (2020), there were 423,666 people in the municipalities of Maringá and 96,688 people in Sarandi, Paraná, in the year of 2019 (estimate). The study area corresponds to the highlighted quadrant exposed in Figure 01, which refers to the location of conurbation between both cities.

Figure 1: Conurbation location map (Maringá-Sarandi, Paraná)



2.2 Acquisition of satellite images and processing of scenes.

The images were acquired from the United States Geological Survey repository. The scenes are from the Landsat 8 satellite, OLI sensor with orbit/point 222/76, referring to the dates 05/01/2013 and 05/04/2020. The scenes were made available in surface reflectance.

The calculation to generate the *Normalized Difference Built-up Land Index* (NDBI) can be seen in equation 01.

$$NDBI = \frac{SWIR - NIR}{SWIR + NIR} \qquad \text{Eq. 01}$$

In which:

NDBI represents the urban spectral index that allows the identification of the areas with the highest density of constructions (Construction index);

NIR corresponds to band 5 of Landsat 8 (reflectance of the near Infrared band);

SWIR corresponds to band 6 of Landsat 8 (reflectance of the medium Infrared band).

To improve the NDBI, Zha et al. (2003) suggested the Built-up index (BU) in order to separate impermeable and permeable areas. This index uses the subtraction of the NDBI and Normalized Difference Vegetation Index (NDVI) indices squared. NDVI can be seen in equation 02 and BU in equation 03.

It should be noted that the NDVI was proposed by Rouse et al. (1973) to highlight the vegetation, thus, the closer to +1, the greater the density of vegetation, and values from 0 to -1 highlight bare land, water depth and built-up areas.

$$NDVI = \frac{NIR - RED}{NIR + RED} \qquad \text{Eq. 02}$$

In which:

NDVI is the vegetation index;

NIR is the reflectance of the near Infrared band;

RED is the reflectance in the red band (Band 4).

$$BU = NDBI^2 - NDVI^2 \qquad \text{Eq. 03}$$

Bands 4, 5 and 6 have a spatial resolution of 30 m. Regarding the wavelength, they differ, because band 4 gives 0.63-0.67 µm, band 5 captures between 0.85-0.88 µm and band 6 between 1.57-1.65 µm.

Image processing was performed using the Qgis program version 3.12.3, using the raster calculator.

3 RESULTS

The results and discussions will be separated into three items to better understand the work. Firstly, the results of NDVI, used to identify the state of vegetation, and necessary to finalize the Built-Up method that will be described. Then, the NDBI of the years 2020 and 2013, in addition to a subtraction map of both in order to analyze the increase in concentrations of

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built-up areas and, finally, the results of the Built-Up method for the years 2013 and 2020 and also a subtraction map for permeability and impermeability analysis.

3.1 NDVI

Considering the following maps (figures 2 and 3), it is possible to identify a mild decrease in the intermediate class between the maps, and in 2020, the NDVI levels were weaker, which shows a possible subtle decrease of around 5.97% in vegetation in the studied area.

Remember that the NDVI method was carried out in order to complement the Built-Up method, since NDVI does not aim to identify urban and conurbated areas.

Highlighted in dark green, it is noted that the class where there is greater density of vegetation is found in the Permanent Preservation Areas (APP) of the first and second order streams scattered throughout the city, in addition to the green areas such as Parque do Ingá and the Bosque two, in the center of Maringá

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Figure 2: NDVI in the year of 2013.

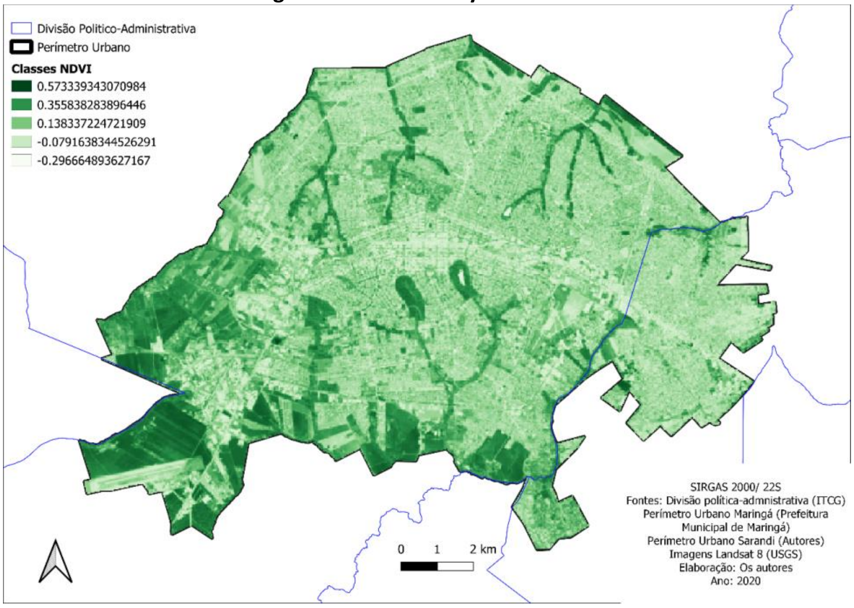
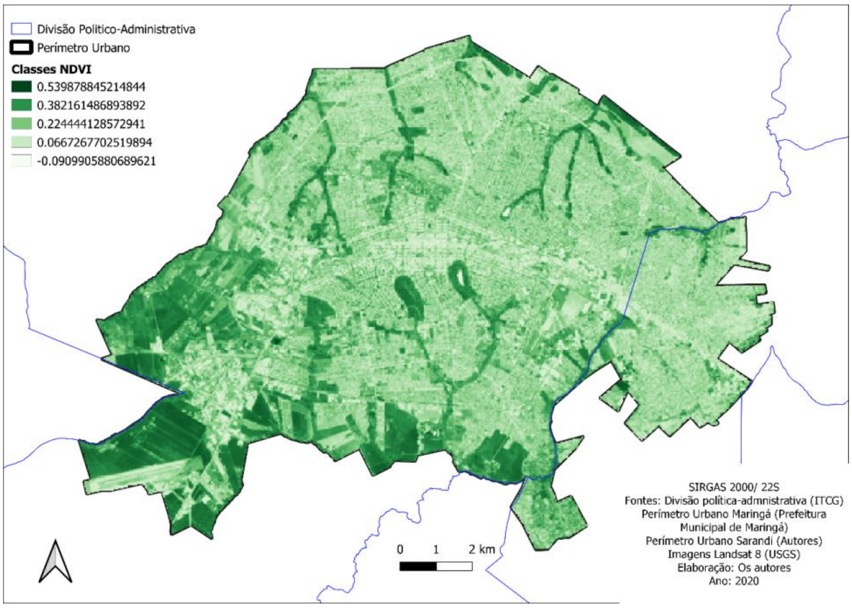


Figure 3: NDVI in the year of 2020



Similar values of NDVI, in Maringá, were entered by Quesada et al. (2017) in riparian vegetation, by Eduvirgem and Ferreira (2018) in the urban area. These values for the urban perimeter may be recurrent in other municipalities, as determined by Toffolli, Rodrigues Junior and Ferreira (2019) in Campo Mourão / PR, Gomes et al. (2019) in Crato / CE.

3.2 NDBI

The NDBI indices presented what was expected by the authors, a thickening in the central west part of the map, in the Maringá - Sarandi disturbance.

There is a great difference between the classes of negative values between one map and another, this may be due to several reasons: marked urbanization, increased paving in the city and the similarity between the reflectances of bare land and urban area, previously mentioned (figures 4 and 5).

Figure 4: NDBI in the year of 2013

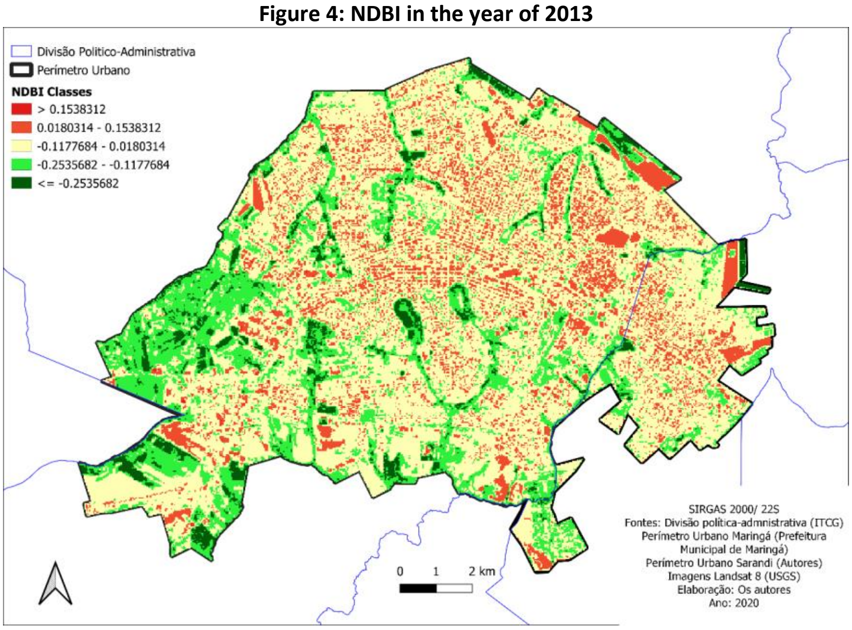
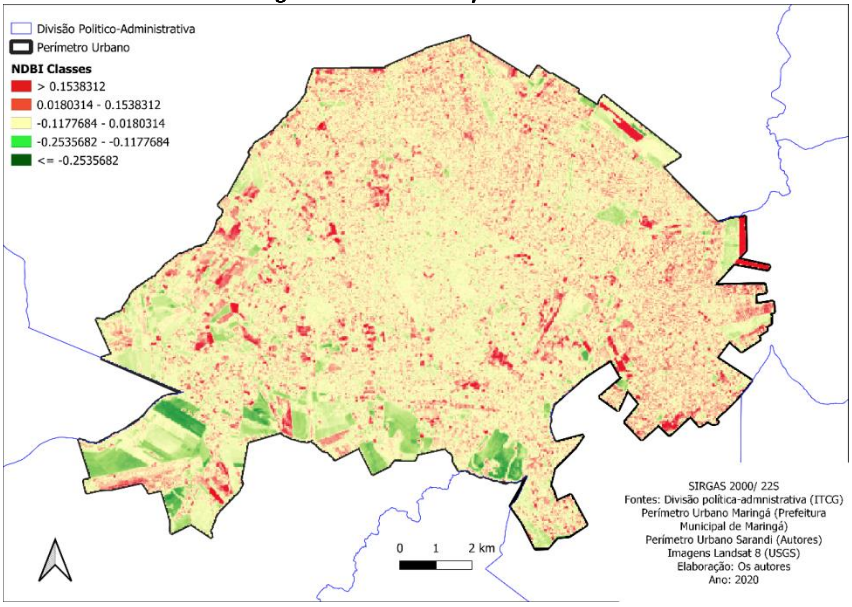


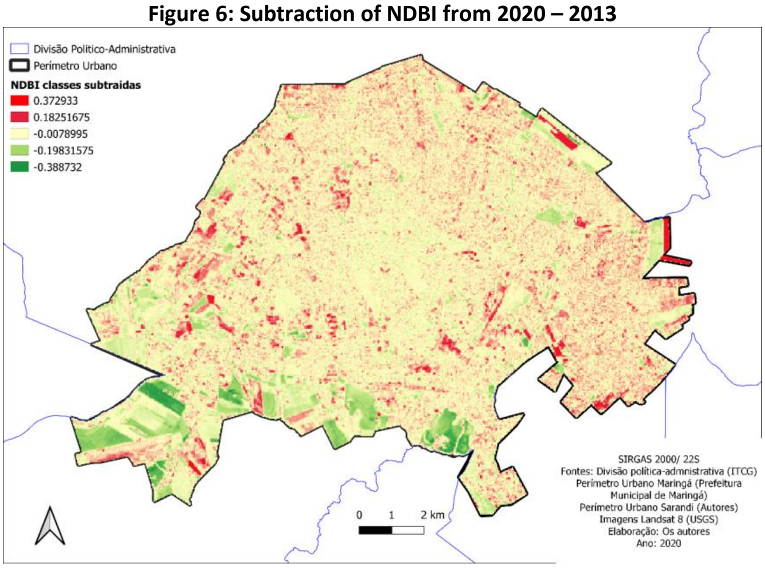
Figure 5: NDBI in the year of 2020



In the difference map between the 2013 - 2020 NDBI, it is noted that the areas in red are the most urbanized in these 7 years, emphasizing both the center-east and the center-west part of the map, the first being the area of conurbation.

The area least affected by urbanization, according to this index, is the southern part of the municipalities, where rural areas still remain over the years, as well as zone 45 to the southwest, which borders rural properties and grain companies on the highway margins, however, these areas are part of the urban area.

Figure 6: Subtraction of NDBI from 2020 – 2013



The maximum NBDI value for both years was 0.153. Close values were determined by Malik, Shukla and Mishra (2019) in Kandaihimmat, India; Leite et al. (2019) in Teresina, Piauí (BR). However, the values can be higher if urbanization presents a higher density than Maringá and Sarandi, as denoted by Benício (2018) in Recife and Jaboatão dos Guararapes, Pernambuco, in which the author identified maximum values between 0.243 to 0.554.

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Santos, Leite and Leda (2017) also expressed the increase in the urban expansion of Bebedouro/SP by spatial analysis - using NDBI, however they showed that the growth was lower when compared to large cities. Maringá and Sarandi presented a similar characteristic because, for the analyzed period, subtle changes were identified, indicating urbanization with an advanced consolidation process, in the perspective of soil waterproofing.

3.3 BUILT-UP

The Built-Up method aims to identify permeable areas (predominantly rural or with vegetation) and impermeable areas (paving and urbanized).

Between the 2013 and 2020 maps (figures 7 and 8), few changes are noted in the permeability according to the scale adopted, however, when it is more detailed, you can find some points to drive your attention to.

In order to make it easier to visualize it and, consequently, to analyse it, a map was elaborated by subtracting both Built-Up (figure 9).

Figure 7: 2013 *Built-up*

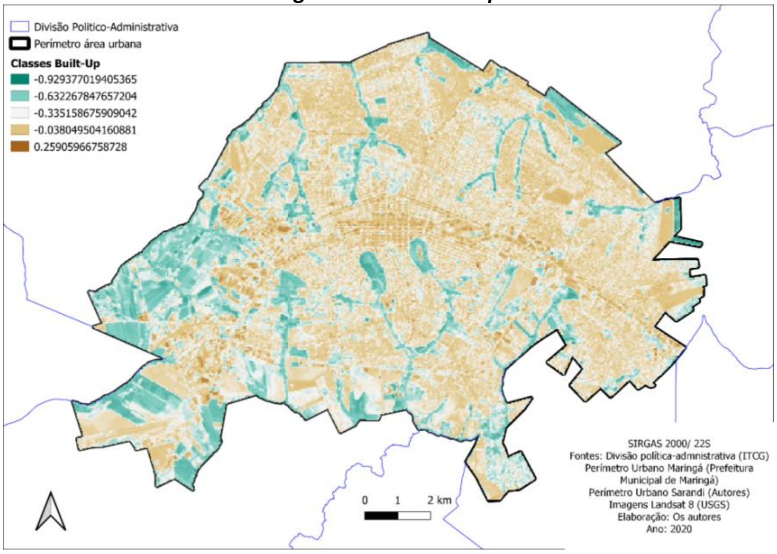
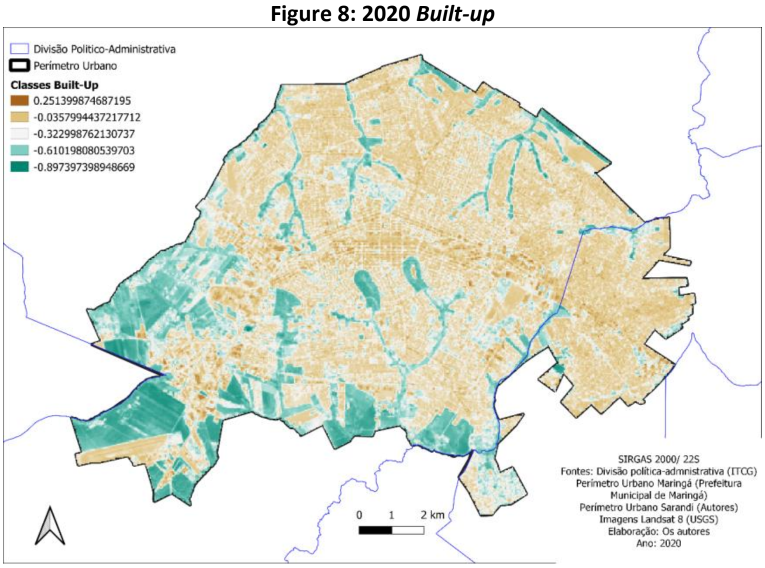


Figure 8: 2020 *Built-up*



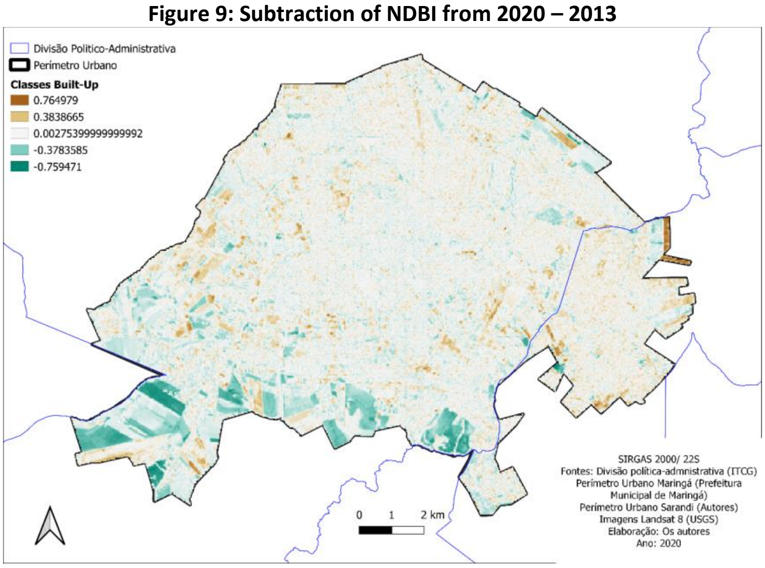
In the map below, the larger the class value, the more impermeable the area has become in these 7 years, that is, the brown classes.

As well as the NDBI index, it is noted that, in the center-east and center-west parts of the map, there are the largest classes, being, respectively, the new industrial districts of Maringá and the studied disturbance.

The green areas represent places where there was no great difference in permeability, that is, in theory, the soil remains permeable, there is little runoff and, consequently, erosion.

In figure 09, it can be seen that to the northeast of the municipality of Sarandi, the greatest intensification of soil waterproofing was determined, because this area consists of the urban expansion of Sarandi.

Figure 9: Subtraction of NDBI from 2020 – 2013



4 CONCLUSION

Considering the results, the densities of the highest classes of NDBI are noted in certain points of the analyzed municipalities, mainly in comparison with the years, when 2020 has built areas of greater proportion than 2013, showing the growth of cities.

Although the indexes are not 100% effective, because the NDBI considers part of bare land as high value, confusing it with the built area, it is proven that, even so, it is considered the best index to identify urban area, not only for this work, but also for the literature. In order to simplify the analysis and to show the bare land areas better, the Built-up method was used, which was compared with the NDBI maps. The Built-up method proved to be efficient in the purpose for which it was developed, which consists of identifying permeable and impermeable areas.

It was possible to identify the importance and limitations of each index approached. As presented in the literature, the NDBI does not differentiate bare land from the built surface. However, NDVI addresses this shortcoming; for its part, the Built-up showed superior potential in the results. However, it is emphasized that, for a safe approach, the researcher can use all three, one index meets the limitation of the other, allowing to identify more precisely the built areas, in addition to promoting measurement.

It is noted that when an index is generated for two different images, the maximum and minimum values are different, leading the values to different colors. Finally, the color classes between the maps must be of total attention to the researcher; different classes on different maps can cause misinterpretations, which can be harmful to the research.

It is also noted that Maringá has environmental and urban planning problems when it comes to surface runoff in the urban area. This is because the city was planned to dump its rainwater runoff into the first-rate watercourses, which are scattered throughout the city, this causes environmental problems such as erosion, tree felling and other types of vegetation. These facts are unfortunately not known by the population, because they are within the APP's and other areas, where there is hardly any visitation; whose indices have been successful in these areas.

Mainly, considering the fact of the previous paragraph, the methods used here are of fundamental importance for planning and zoning studies.

It is noteworthy that the results generated in this work can assist both in public management, as well as in office research before leaving the field to analyze areas with environmental changes.

It is suggested further studies to be carried out in order to analyze urban expansion, and the reduction of vegetation to be studied on a scale in greater detail. Such an approach is valid, since this theme is related to socio-environmental quality.

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