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Changes in Soil Coverage in Teresina City, Piauí State, Brazil

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Abstract

Impacts from vegetation cover and soil sealing stand out in the urban expansion process, since these factors represent elements indicative of urban environmental quality. Unorganized growth in cities that keep their dynamism and attractiveness due to accelerated population growth associated with more soil occupation can be an issue. Teresina City, which is the capital of Piauí State, faces difficulties just as any other Brazilian city; it stands out for growing and spread urban expansion. The aim of the present article is to analyze urban expansion and soil coverage changes in Teresina City, Piauí State, Brazil, by taking into account the years of 2000, 2010 and 2015. Landsat satellite images were interpreted to assess urban soil coverage. The Digital Image Processing (DIP) procedure used the SPRING software (5.1.8) - System for Processing Georeferenced Information - by the National Institute for Space Research (INPE). Software ArcGIS (10.3) was adopted to generate thematic maps. Teresina City presented an accelerated urban expansion process, without balance between soil sealing and vegetated soils. The sealing of large urban soil areas in Teresina, in addition to great vegetal cover losses and to unequal distribution population and basic services distribution, have pointed out that the urbanization process has not been sustainable.

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INTRODUCTION

Urbanization growth over natural spaces, where cities expand in rarefied fashion, oftentimes present unequal population distribution, with poor and rich zones, and with deprived areas and other areas well-served with equipment. This unorganized expansion process brings along some consequences, such as excessive expenses with urban infrastructure, and loss of both permeable spaces and natural vegetation.

Urbanization implies changes in natural environment, and this process must be taken into account within several geographic and historical contexts. According to Catalán, Sauri and Serra (2008), matters linked to urban sustainability, organization and growth must take into account other systems, like the economic matters of territories' activity and competitiveness, social issues, the democratic access to cities and socio-spatial segregation, as well as governability issues associated with city-structure maintenance.

However, with respect to environmental impacts, the most evident expression lies on vegetation reduction. Vegetal coverage in urban areas is the most important indicator of changes in environmental balance and quality (ZHOU; WANG, 2011; ZHAO et al., 2013).

Green areas are important elements for pollution reduction and for water spring protection. They also contribute to control solar radiation, evapotranspiration, moisture, air temperature, the action of wind and rain, air pollution filtering, and shading (MACHADO; PEREIRA; ANDRADE, 2010; FEITOSA et al., 2011; STREGLIO; FERREIRA; OLIVEIRA, 2013).

Altunkasa et al. (2017) associated the presence of green areas with benefits such as air purification, groundwater reloading, erosion prevention, besides collaborating to leisure. According to Zhou; Wang (2011), besides the aforementioned aspects, one finds the aesthetic and leisure pleasures, which contribute to physical and psychological well-being.

Soil sealing is another important action associated with vegetal coverage loss within the urban expansion process. According to Sperandelli, Dupas; Pons (2013) and Kemerich et al. (2014), urban growth implies impermeable areas' increase, which decreases the infiltration process and makes rainwater flow faster. This process changes flood systems and increases sedimentation in reservoirs and watercourses. These factors, in their turn, imply lower water quality, terrain stability and water system functioning.

Londe and Mendes (2014) point out that different functions by vegetal coverage - be them environmental, social or psychological – mitigate urbanization consequences and contribute to improve the quality of the urban space, a fact that justifies their permanence and further studies in this field.

Green area, outdoor spaces and vegetal coverage are terms, oftentimes, used as synonyms. We herein used the term vegetated soil or vegetal coverage, since the idea was to distinguish plant size (herbaceous, shrub or arboreal) from original vegetation (natural or cultivated) or its domain (public or private), based on Moura and Nucci (2008) and Machado, Pereira and Andrade (2010).

Vegetation removal associated with urban expansion is common in most Brazilian cities, as it has been also happening in Teresina City, the capital of Piauí State. According to Feitosa et al. (2011), the city has been losing vegetal coverage, and it has been compromising shading and thermal comfort in its urban area. As for Lima, Lopes and Façanha (2017), Teresina has been facing accelerated growth, either of its population or of its urban area, due to rarefied and spread occupation.

Maximum temperatures reach 40°C in the warmest period in Teresina, from October to December. According to Andrade (2016, p. 16), this period is seen as "the most emblematic time of the year for the city, given the atmospheric conditions favorable for the increment of high temperatures and for the worsening of human thermal discomfort". It is important highlighting that vegetation presence in dry and hot climate locations is an essential factor to improve environmental comfort (ROCHA; NUCCI, 2019). This statement justifies the need of vegetated areas in its territory.

The aim of the present article was to analyze urban expansion and soil coverage changes in Teresina City, Piauí State, by taking into account the years of 2000, 2010 and 2015.

METHODOLOGY

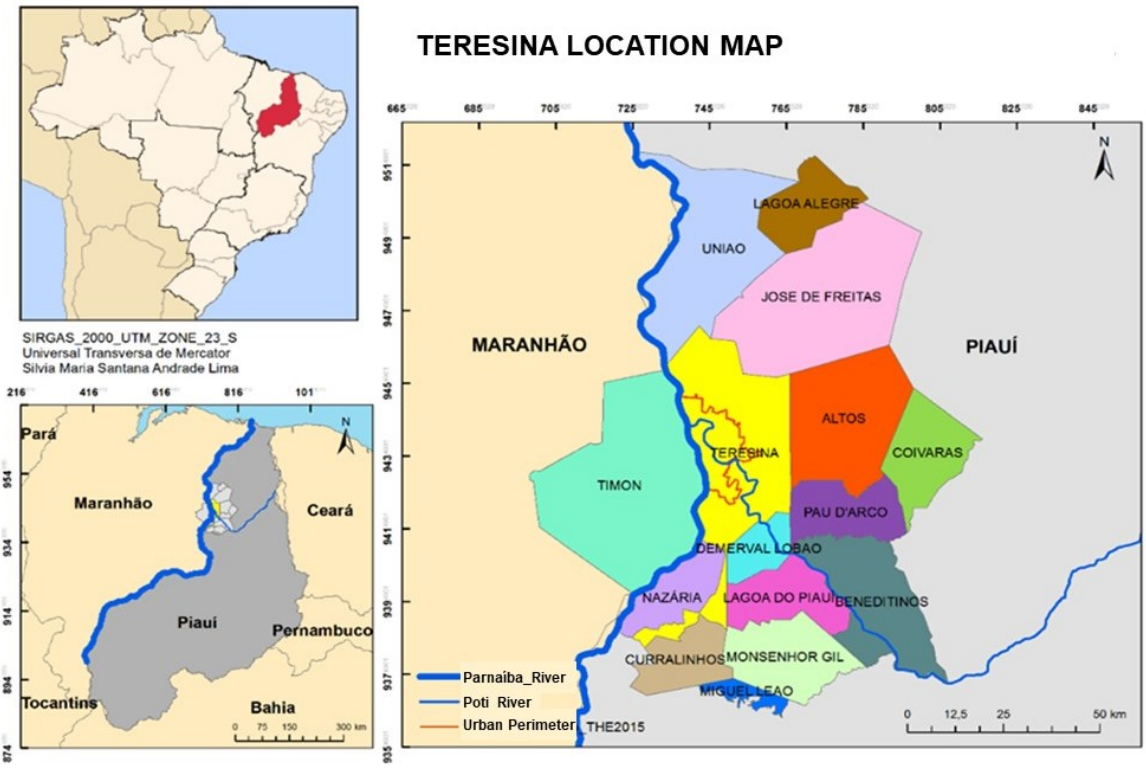
Teresina City holds more the ¼ of the population in Piauí State; estimates show 868,755 inhabitants by 2020; accumulated growth between 2000 and 2015 reached 18.2% – it presented a territorial area of 1,391.046 km² (IBGE, 2020).

The capital of Piauí State presents tropical – it is among the warmest in Brazil - and sub-tropical climate. The recorded temperatures are high; they range from 22º C to 40º C. Rainfall distribution is quite irregular, with annual mean of 1,332 mm, mainly in the rainy season, from December to May. Months from August to November are the driest ones (TERESINA, 2010).

Vegetation in Teresina is of the morphoclimatic domain – transition from *cerrado* to *caatinga* and Amazonian domain. According to Andrade (2016, p. 409), the city is full of "landscape islands" that cover coconut forests and *caatinga*, alternated with *cerrado* and forests. It is located at geographic coordinates 05º05'20" S latitude and 42º48'07" W longitude, at mean height of 72m above sea level. It lays on the sides of Parnaíba River, which separates Piauí State from Maranhão State – it is also crossed by Poti River. It is the only capital in the Northeastern region that is not located on the coast – it is 366 Km away from the coastal shore.

Teresina, and the following counties: Altos, Beneditinos, Coivaras, Curralinhos, Demerval Lobão, José de Freitas, Lagoa Alegre, Lagoa do Piauí, Miguel Leão, Monsenhor Gil, União, Pau D'arco do Piauí and Nazária, in Piauí State, besides Timon, in Maranhão State, form *Região Integrada de Desenvolvimento (RIDE) da Grande Teresina* (Integrated Development Region (RIDE) of Big Teresina) (Figure 1), which was created by Decree-law n. 4.367, from September 9, 2002 (BRASIL, 2002).

Figure 1 - Teresina Location Map



Source: Malha Digital Setores Censitários, IBGE (2010c)

LANDSAT 7 images, sensor Thematic Mapper (TM), at 30m spatial resolution and 7 spectral bands, and LANDSAT 8 OLI (Operational Terra Images), with 9 multi-spectral bands at a spatial resolution of 30m and 15m, were used to assess urban soil coverage (SANTOS, 2013).

Digital Image Processing (DIP) procedure was carried out in SPRING software (5.1.8) - System for Processing Georeferenced Information -, by the Instituto Nacional de Pesquisas Espaciais - INPE (National Institute for Space Research). Thematic maps were plotted in ArcGIS software (10.3).

Images were taken for free on the website of USGS (U S. Geological Survey) – system orthorectification was conducted through UTM cartographic projection and Datum WGS84, which were reprogramed for SIRGAS_2000_UTM. They were acquired in grayscale format of special bands 1, 2, 3, 4, 5 and 7 of the Landsat 7 TM satellite for the years of 2000 (August 28, 2000) and 2010 (July 21, 2010); as well as bands 2, 3, 4, 5, 6, and 7 of the Landsat

8 OLI satellite for the year of 2015 (October 25, 2015).

Images taken in the second semester of each of the assessed years were selected for better resolution. This time of the year is featured as the driest one in the region, it also accounts for the lowest cloud coverage – two scenes were selected for each, one at orbit/point 219/63 and another at orbit/point 219/64. It was done in order to cover the whole urban zone in Teresina City, which was defined by the last perimeter, through law n. 4.831, from 2015 (TERESINA, 2015b).

Google Earth software was also used to compare satellite images to some elements that were not well-defined. Chart 1 shows the features of the acquired images.

Chart 1 - Features of the used satellite images

	IMAGE	SPECTRAL RESOLUTI ON	BANDS	SPATIAL RESOLUTI ON	DATE	ORBIT /POINT
2000	LANDSAT 7, Thematic Mapper (TM)	7 spectral bands	1, 2, 3, 4, 5 AND 7 (RGB 5, 4, 3)	30 m	08/28th/20 00	219/63 and 219/64
2010	LANDSAT 7, Thematic Mapper (TM)	7 spectral bands	1, 2, 3, 4, 5 and 7 (RGB 5, 4, 3)	30 m	07/21st/20 10	219/63 and 219/64
2015	LANDSAT 8 OLI, Operacional Terra Imager	9 spectral bands	2, 3, 4, 5, 6, and 7 (RGB 4, 5, 6)	30m and 15m	10/25th/20 15	219/63 and 219/64

Source: The authors.

Treatment was carried out in SPRING (5.1.8) in order to get better quality images. A database was created and two images from each year were inserted in it (orbit/point 219/63 and orbit/point 219/64) – the fusion of these images was also performed. Finally, images were cut based on the shapefile of Teresina's urban perimeter in 2015, which was drawn in CAD and georeferenced – it was acquired in Teresina's City Hall (TERESINA, 2015b); only the area of interest for the analysis was acquired.

The following soil coverage classes were chosen: Vegetated Soil, Exposed Soil, Waterbodies and Urbanized Soil, which are important indicators of urban environment quality. Chart 2 presents the classes and targets of interest used in the study in order to make the understanding easier.

Chart 2 - Definition of targets of interest

	CLASS	DESCRIPTION
1	Vegetated	Non-deforested regions with dense vegetation, mid-sized and/or undergrowth vegetation
2	Exposes soil	Area free from buildings without vegetation coverage
3	Waterbodies	Rivers and lagoons.
4	Urbanized soil	Asphalt, pavement, ceramic roofing, metallic roofing, built-up area

Source: The authors.

The Supervised Classification method was used to map the areas of interest. This method consists in extracting information from images in order to find homogeneous patterns and objects based on data that allow identifying a class of interest. A composition with EGB color filter (RED, GREEN, BLUE) at spectral bands 5, 4 and 3, for the years of 200 and 2010, and at bands 4, 5 and 6, for the year of 2016 was set to improve the distinction between elements of interest, since it has generated a fake-color composition. In other words, these images were artificially colored to highlight the observed changes (MORATO et al., 2011).

The categories defined for the classification allowed the performance of a first supervised test by selecting small, homogeneous and representative samples of each class in order to avoid confusion among them. Classifier MAXVER (Maximum Likelihood), which takes into account the weight of distances between the mean of classes' digital levels, was used to analyze the quality of the acquired samples based on statistical parameters. It was possible stating that samples were satisfactory by assessing the mean performance of classification, since they pointed out performance higher than 93%.

The classification process resulted in the quantification of values associated with the classes analyzed in hectares, since it led to the outcomes observed in the assessed territorial area, which refer to classes "vegetated soil", "Exposed Soil", "Waterbodies", and "Urbanized Soil".

Besides the classification, data segmentation between regions was also used. Regions were classified based on the distribution of urban spots consolidated by cardinal points between the initial core (urban polygon representing the condition observed in 2000) in each region, and, in this same area, in 2010 and 2015, as recommended by Inostroza, Baur and Csaplovics (2013).

Seven regions called Central, South, Far South, Southeast, East, Northeast and North were divided and taken into account for the analysis; these regions are different from the current administrative division by Teresina City Hall (Center-North, South, East and Southeast), since the managerial sectors do not consider the continuity of urban spots and groups segmented spaces within the same region based on demographic gaps, or they are separated by roads or divided by rivers.

RESULTS AND DISCUSSION

Teresina City's territorial area, based on the 2015 perimeter, which was defined by law n. 4.831 (TERESINA, 2015b), showed permeable soil loss by 31.38% (vegetated soils and exposed soils) between 2000 and 2015. The permeable area that covered 72.18% of the urban territory in 2000 was reduced to 49.52% in 2015, and impermeable soils (urbanized soils) increased by 86.74%.

Table 1 - Soil Coverage Categories in hectares and the rate of occupied urban area in 2000, 2010 and 2015.

TERESINA	AREA IN HECTARE			AREA RATE		
	2000	**2010**	**2015**	**% in 2000**	**% in 2010**	**% in 2015**
Urbanized soil	7,003.08	10,759.68	13,077.45	26.45	40.64	49.39
Vegetated soil	17,293.59	13,681.00	10,046.34	65.32	51.68	37.94
Exposed soil	1,815.75	1,646.10	3,065.22	6.86	6.22	11.58
Rivers and Lagoons	363.33	387.99	286.74	1.37	1.46	1.09
TOTAL	**26,475.75**			**100%**		

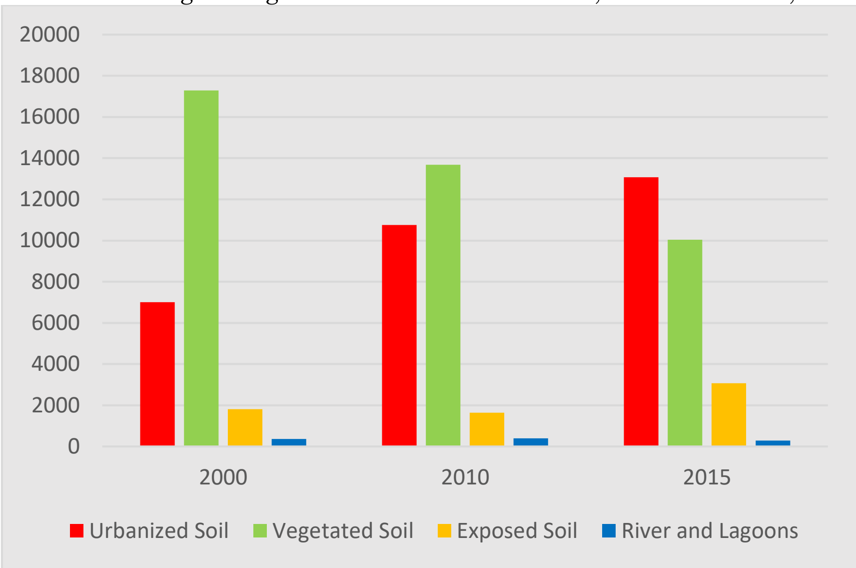
Source: Dados Imagens LANDSAT 7_TM and LANDSAT 8_OLI, USGS; TERESINA (2015a), processed in SPRING and ArcGIS (10.3)

It is possible observing that urbanized areas have increased more than the number of inhabitants by comparing population growth in Teresina between 2000 and 2010 and between 2000 and 2015 (IBGE, 2010; IBGE, 2015). Population growth rate, within a 10-year period of time (2000-2010), reached 13.30%, and urbanized soils rose by 53.64%. Yet, if one takes into consideration the 15-year period of time (2000-2015), demographic growth was close to 18.02% and impermeable soil growth increased by 86.74%.

It is possible observing that, among the herein assessed classes and categories, the fraction concerning urbanized soils was the one recording the highest growth: 26.45% occupation in 2000 and 40.64%, in 2010. On the other hand, the greatest losses are observed in vegetated soil categories, which covered 65.32% of the urban territory in 2000 and only 51.68% of it in 2010. Exposed soil between 200 and 2010 dropped from 6.86% to 6.22% of the total urban area. It is essential pointing out that exposed soil variation means vegetation cover loss, or yet points towards deforestation for further occupation by buildings.

Figure 2 clearly shows that the urbanized soil was the soil class mostly growing within the assessed time-lapse, whereas soil coverage was the one recording the greatest loss – the loss process got faster in the last five years.

Figure 2 - Soil coverage categories for Teresina in 2000, 2010 and 2015, in hectares



Source: Imagens LANDSAT 7_TM and LANDSAT 8_OLI, USGS (2000, 2010, 2015); TERESINA (2015a)

Urbanized soils in 2000 covered 26.45% of Teresina's territory and this soil category accounted for 49.39% of it in 2015. Areas presenting vegetation cover would represent 65.32% of the territory in 2000 and vegetated soils in 2015 would represent 37.94% of the urban space. The vegetal cover lost between 2000 and 2010 is similar to that recorded between 2010 and 2015, in half of the time (five years). Another relevant datum observed between 2010 and 2015 is the increase in the rate of exposed soil, which rose from 6.22% to 11.58% of the urban area.

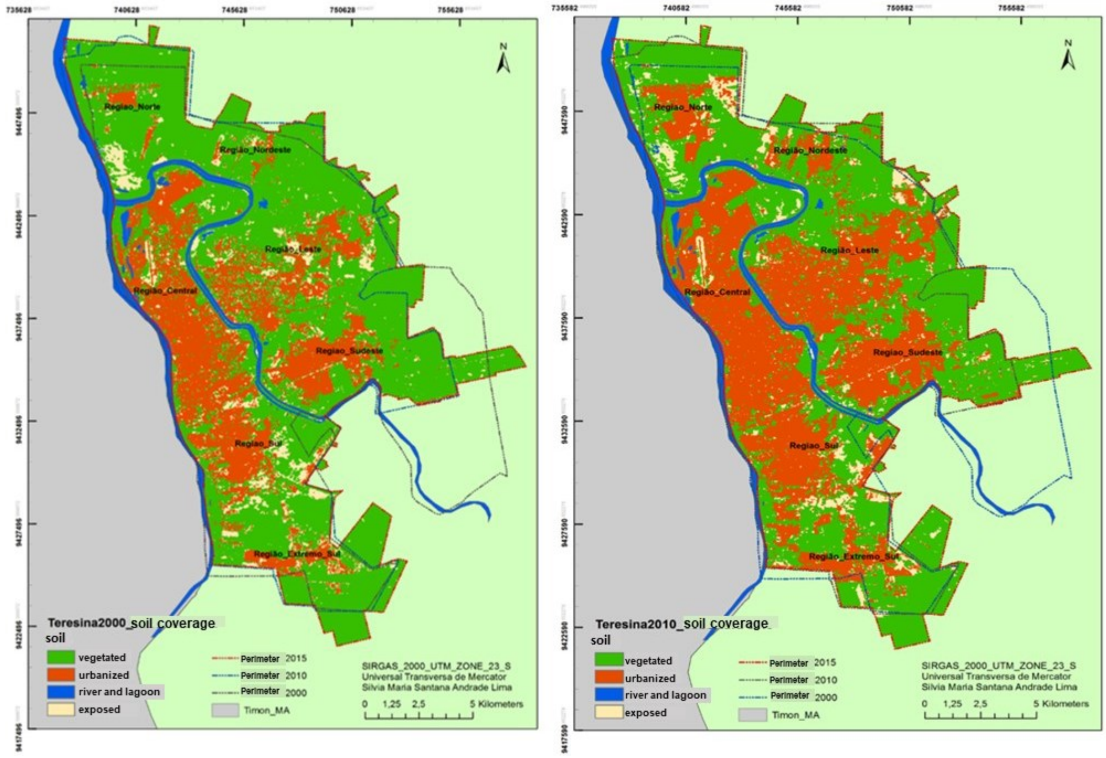
The significant increase in the exposed soil rate and the drop in vegetation cover, between 2010 and 2015, observed in Teresina, can be related to the implementation of new allotments, since one of the arguments of the City Hall was that changes in urban perimeter (TERESINA, 2015b) were caused by new occupations.

Previous research about Teresina's urban zone has recorded reduction in its vegetation cover. Machado, Pereira and Andrade (2010), identified vegetation cover loss by 12.73%, and 13 km² (1.300,00 hectares), between 2000 and 2006. Feitosa et al. (2011) observed a drop by 29.69% in vegetation cover, and this number corresponds to approximately 48.3 km² (4,830.00 hectares) of vegetated soil between 1989 and 2009. The aforementioned research took into account the territorial urban area of 27,502.68 hectares, which referred to the perimeter in 2000; it was 25,084.36 hectares, in 2010. The territorial area of the urban perimeter defined in 2015 was also taken into consideration, it corresponds to 26,411.95 hectares.

The difference observed between the assessed perimeters, besides the different images, dates, satellites and resolutions may have affected the results; however, it is important highlighting that all studies have pointed towards losses and reduction in Teresina's vegetation cover due to urban expansion. Between 2000 and 2015, there was an increase by 6,074.37 hectares in urbanized soil coverage, and it is equivalent to 86.74% growth; the vegetation area faced the suppression of 7,247.25 hectares.

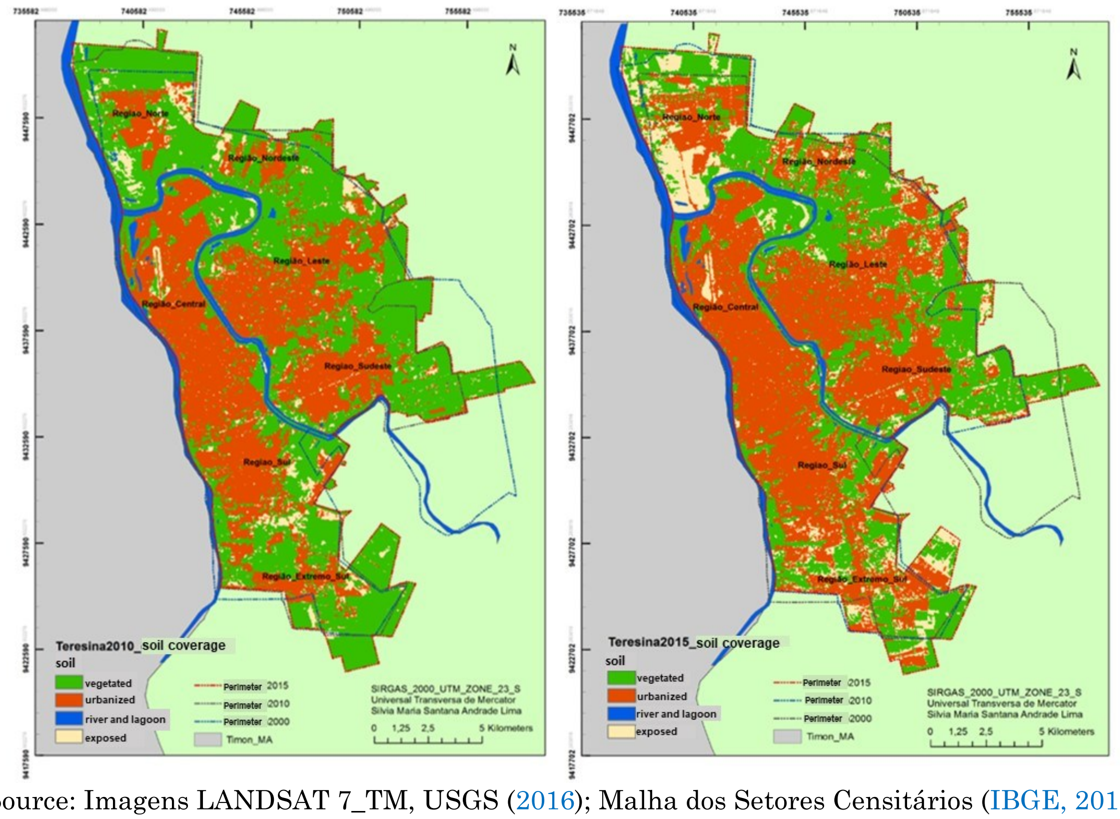
Almost 50% of Teresina City is covered by impermeable spaces and less than 40% of its soils are covered by vegetation. Changes in the city's urban soil coverage and in its space can be observed in Figure 3, for 2000 and 2010, and in Figure 4, for 2010 and 2015.

Figure 3 - Map of urban soil coverage in Teresina (PI) in 2000 and 2010.



Source: Imagens LANDSAT 7_TM, USGS (2016); Malha dos Setores Censitários IBGE (2000c, 2010c) TERESINA (2015a), processed in SPRING and ArcGIS (10.3)

Figure 4 - Map of urban soil coverage in Teresina – PI – 2010, 2015



Source: Imagens LANDSAT 7_TM, USGS (2016); Malha dos Setores Censitários (IBGE, 2010c), TERESINA (2015a), processed in SPRING and ArcGIS (10.3)

Continuous urban spots represented by the reddish shades have grown and tend to gather and form urban sectors around the downtown area, and it will produce well-defined agglomerates that will be distributed among the North, Northeast, East, Southeast, South and far South regions. They will be separated by empty spaces with buildings and urbanization, which are depicted in green and in light color shades. Thus, it is clear that Teresina has been facing the growth of impermeable soil areas and the reduction of vegetal cover.

All groups of urban spots, represented in red, show vegetated and exposed soils spread within the urbanized space, which are observed through the green and light color shade points between red spots. Consolidated spots presenting smaller vegetated space intercurrences can be observed in the Southeast region and they correspond to the following neighborhoods: Itararé, Parque Ideal, Renascença. Similar aspects are also seen to the North of the Central region, and they concern the neighborhood known as Mocambinho.

It is possible observing that, back in 2000 (Figure 3), Teresina presented consolidated urban spots at continuous arrangements distributed into sectors around spaces between rivers, and Central region presenting interspersed and isolated arrangements to the South of the city, which represent the following neighborhoods: Saci, Parque Piauí, Lourival Parente, Promorar, among others. As for the far South, urbanized areas were smaller, with emphasis on neighborhoods Angelim and Esplanada. When it comes to areas upstream of Poti River, one can see small spots of urbanized soils to the North of the city, which were formed by the following neighborhoods: Santa Maria da Codipi, Parque Brasil – to the Northeast of the city one can only observe the neighborhood known as Pedra Mole. The other groups of urban spots, which were more consolidated, were located in the East and Southeast regions.

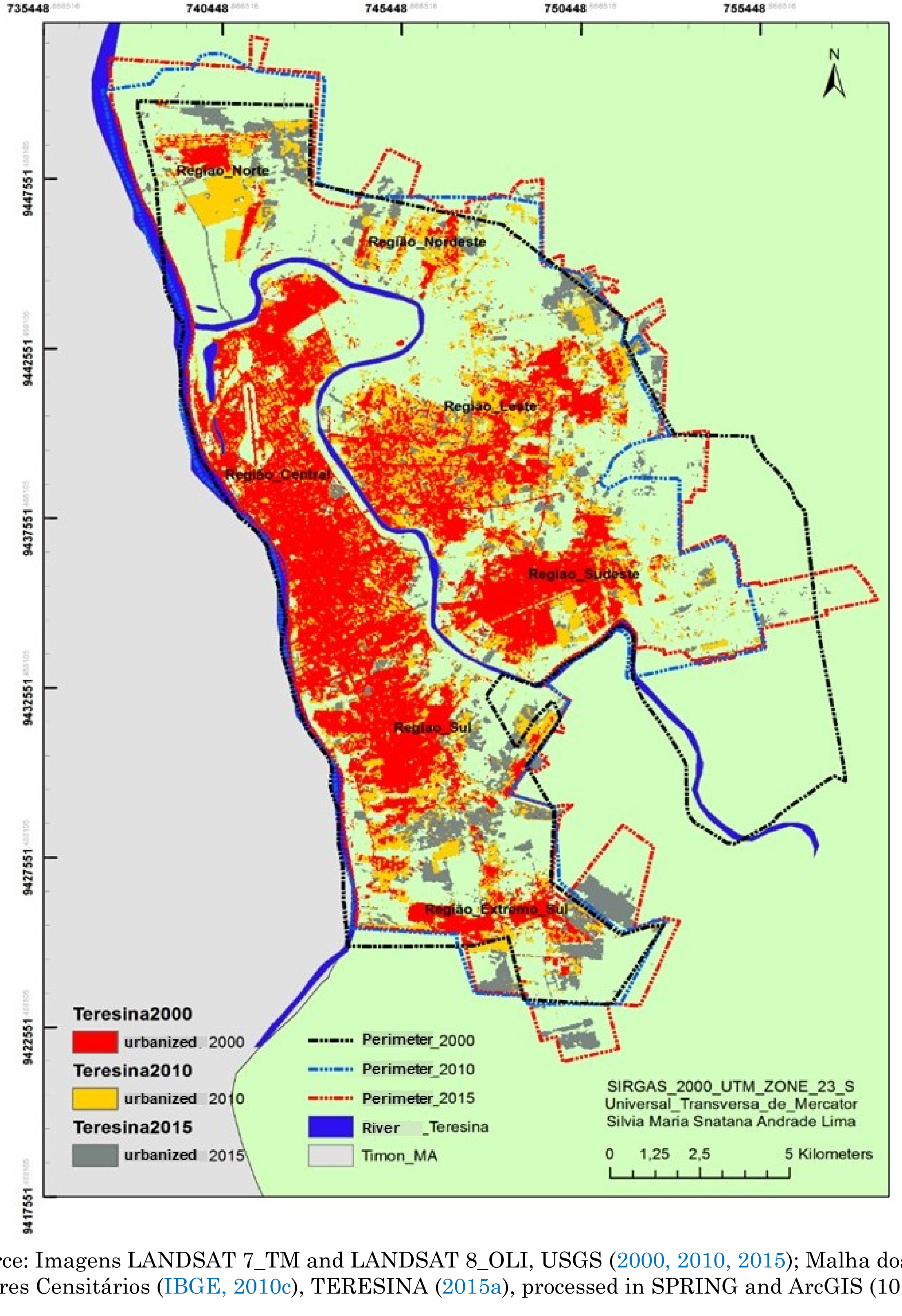
The year of 2010 (Figures 3 and 4) shows increase in reddish pots to the North, Northeast and Far South of Teresina City, as well as growth and consolidation of urbanized spots in the Central region. There was a trend of union between reddish urban spots and reduction in vegetated soils (depicted in green). It is possible observing that vegetation cover rate also dropped within the consolidated built mesh, which became smaller at each of the assessed periods of time, 2010 and 2015 (Figure 4).

It was observed that growth and agglutination between urban spots got more intense in 2015 (Figure 4), and it was also possible to see a certain isolation of reddish spots in the North and Northeast regions, which remained surrounded by soils with vegetation cover. The other regions showed trend of urbanized areas' expansion and agglutination. One can observe that in 2015 there was increase in the rate of exposed soils, which is represented by the light color shades. This frame can point towards a deforestation process for new allotments; it can also be the result of low rainfall rates in the last few years or from the increase in the number of burns in these regions – all these aspects affect the coverage of vegetated and exposed soils.

Vegetation loss is much more representative in areas around the consolidated spots, and it highlights urbanization widespread and greater expansion of built soils. The increased rate of impermeable soils is worrisome, since, as highlighted by Seto et al. (2011), it implies losses and disturbances in species' habitat or, yet, as observed by Garotti and Barbassa (2010), it is an important parameter to measure urbanization impacts.

The West region is the one presenting the largest area covered by urbanization spots within the consolidated urban spot. It can be more clearly observed through the overlap of built soils during the three periods, 2000, 2010 and 2015 (Figure 5).

Figure 5 - Map with the Evolution of Urban Spots in Teresina in 2000, 2010 and 2015, based on the classification of urban soil coverage images.



Source: Imagens LANDSAT 7_TM and LANDSAT 8_OLI, USGS (2000, 2010, 2015); Malha dos Setores Censitários (IBGE, 2010c), TERESINA (2015a), processed in SPRING and ArcGIS (10.3)

Figure 5 shows the presence of yellowish spots in the East region, which represents the expansion observed in 2010; grayish shades represent the expansion in 2015, within the red spot, which, in its turn, corresponds to the urban spot situation in 2000. This finding points out greater occupation inside the urban spot. The East region is quite valorized, the richest population looks for real estate in it; according to Reis Filho (2012), this region has been promising for expansion and for great real estate investments, since the 1970s.

The greatest growth in areas located to the North and far South of Teresina City was observed in 2015 (Figure 15), which are regions featured by the presence of gray spots. As for the other regions, the grayish shades prevail inside the red and yellow spots of the previous urban scenario (2000-2010). This finding points towards greater spreading in the North, Far South and peripheral regions. There was intra-urban occupation in the other regions, besides the occupation of their peripheries. Thus, it is possible observing greater soil consumption, soil sealing and spreading than densification and, consequently, greater vegetation cover loss.

The observation of population density indices in these regions between 2000 and 2010 also reinforce the present findings. The region in the Far South Teresina polygon is mostly formed by low-income families' housing estates, villages (spontaneous occupation without infrastructure) and parks (groups of houses on streets without the least of expected infrastructure) (Teresina, 2017). Angelim neighborhood is located in this region, it is one of the biggest neighborhoods in the territorial area. Angelim started in an old cattle farm, which was integrated into the urban area in 1988. This neighborhood holds Irmã Dulce Village, one of the biggest occupation areas in the city, which was launched in 1998 – back in 2010 it held 14,222 inhabitants (IBGE, 2010a).

This polygon was the one accounting for the greatest reduction in density, which dropped from 69.43 inhab./ha to 24.60 inhab./ha. However, this region to the far South of Teresina City was the one presenting the greatest expansion in its occupied territory, from 250.14 hectares to 1,668.27 hectares – and it explains the density decrease.

Mascaró and Mascaró (2001) have recommended densification in mid-sized Brazilian cities without increasing the demand for infrastructure, density values of 350 inhab./ha – at most – and 40 inhab./ha – at least -, although they confirm that there are no ideal indices.

Accordingly, one can observe that Teresina City is far from what Lehmann (2016) calls "densification with quality", which joints densification and vegetation areas. In other words, urbanization impacts will only be beaten by mitigation strategies, among other aspects, that include the preservation of natural resources, such as vegetation cover areas. Thus, Riffat, Powell and Aydin (2016) state that, in order to configure sustainable urbanizations, it is essential joining the efficient use of resources to opportunities, as well as to a design of compact cities with lower urbanization costs and to increased vegetation areas, among other strategies.

Changes in urban soil coverage by region better represent such a differentiated partition. Table 2 only shows the Urbanized Soil, Vegetated and Exposed Soil categories, and disregards waterbodies, and it would explore the non-closing of rates in 100%.

Table 2 - Soil coverage categories by region, expressed in hectares, rate of the occupied region's area in 2000, 2010 and 2015, and growth rate 2000-2015

REGION	PERIOD	AREA IN HECTARE			REGION RATE		
		Urbanized	Vegetated	Exposed	% urb	% veg	% exp
Central	2000	2,741.05	1,539.23	271.43	59.68	33.51	5.51
4,592.65 ha	2010	3,290.57	1,079.25	185.48	71.65	23.50	4.04
	2015	3,415.66	894.66	244.26	74.37	19.48	5.32
South growth	**2000/2015**	**674.61 há**	**-644.57 ha**	**-27.17 ha**	**24.61%**	**-41.88%**	**-10.01%**
	2000	958.75	1,152.88	332.86	39.18	47.11	13.60
2,446.92 ha	2010	1,372.41	882.54	187.28	56.09	36.07	7.65
	2015	1,651.22	673.82	119.81	67.48	27.54	4.90
	2000/2015	**692.47 há**	**-479.06 ha**	**-213.05 ha**	**72.23%**	**-41.55%**	**-64.01%**
Far South	2000	472.78	3,203.95	291.51	11.91	80.71	7.34
3,969.96 ha	2010	891.50	2,735.94	340.90	22.46	68.92	8.59
	2015	1,590.96	1,624.18	753.91	40.07	40.91	18.99
	2000/2015	**1,118.18 há**	**-1,579.80 ha**	**462.40 ha**	**236.51%**	**-49.31%**	**158.62%**
Southeast	2000	1,049.09	3,328.29	180.13	22.98	72.91	3.95
4,565.17 ha	2010	1,579.58	2,785.45	183.65	34.60	61.01	4.02
	2015	1,862.71	2,289.20	403.70	40.80	50.15	8.84
	2000/2015	**813.62 há**	**-1,039.10 ha**	**223.57 ha**	**77.55%**	**-31.22%**	**124.12%**
East	2000	1,368.37	3,291.42	449.97	26.54	63.84	8.73
5,155.86 ha	2010	2,562.71	2,272.19	264.87	49.71	44.07	5.14
	2015	2,906.54	1,867.32	355.35	56.37	36.22	6.89
	2000/2015	**1,538.17 há**	**-1,424.10 ha**	**-94.62 ha**	**112.41%**	**-43.27%**	**-21.03%**
Northeast	2000	120.03	1,744.20	71.41	6.20	90.05	3.69
1,936.81 ha	2010	382.16	1,428.68	118.50	19.73	73.76	6.12
	2015	530.11	1,205.54	195.94	27.37	62.24	10.12
	2000/2015	**410.08 há**	**-538.66 ha**	**124.53 ha**	**341.65%**	**-30.88%**	**174.39%**
North	2000	190.96	2,824.35	263.48	5.77	85.37	7.96
3,308.47 ha	2010	614.92	2,281.23	389.23	18.59	68.95	11.76
	2015	945.78	1,259.32	1084.78	28.58	38.07	32.79
	2000/2015	**754.82 ha**	**-1,565.03 ha**	**821.30 ha**	**395.28%**	**-55.41%**	**311.71%**

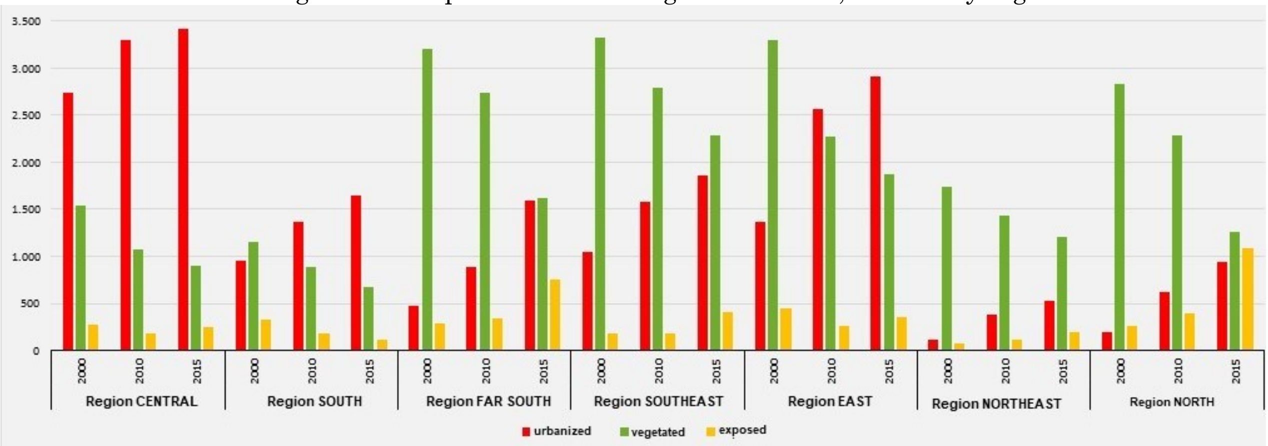
Source: Imagens Landsat, USGS (2000, 2010, 2015); TERESINA (2015a), processed in SPRING and ArcGIS (10.3)

Urbanized spaces that have presented the greatest territorial growth were the East (5,155.86 hectares), Central (4,592.65 hectares) and Southeast (4,565.17 hectares) regions. Subsequently, one finds The Far South (3,969.96 hectares), North (3,308.47 hectares), South (2,446.92 hectares) and Northeast (1,936.81 hectares) regions.

Regions presenting the highest rates of urbanized soil in 2015, in terms of territorial areas, were the Central (74.37%), South (67.48%) and East (56.37%) regions. The ones accounting for the lowest urbanized soil rates were the Northeast (27.37%) and North (28.58%) regions. The South and Far South regions reported 40.07% and 40.80% of urbanized area, respectively. Regions accounting for the lowest urbanized soil rates were the ones recording greater growth between 2000 and 2015: North (395.28%), Northeast (341.65%) and Far South (236.51%). In territorial terms, regions that have recorded the highest increase in urbanized soils were East (1.538,17 hectares), far South (1.118,18 hectares), Southeast (813,62 hectares) and North (754,82 hectares). Regions accounting for the lowest growth in urbanized soil rate between 2000 and 2015 were the Central (24.61%), South (72.23%) and Southeast (77.55%) regions. The greatest soil vegetation cover losses were observed in the North (55.41%), Far South (49.31%) and East (43.27%) regions.

It was also observed that the most expressive growth in urbanized soil among the Central, South, Southeast and East consolidated regions took place in the East region, whereas areas accounting for the more recent urbanization, such as the North, Northeast and far South regions, presented more significant urbanized soil expansion – vegetated soil reduction and exposed soil increase was quite perceptible (Figure 6).

Figure 6 - Graphic of soil coverage in Teresina, divided by region.



Source: Imagens LANDSAT 7_TM and LANDSAT 8_OLI, USGS (2000, 2010 and 2015), TERESINA (2015a), processed in SPRING and ArcGIS (10.3)

The Far South and North regions, besides reduction in vegetation coverage, have their exposed soil areas doubled between 2010 and 2015. These Teresina regions, which are located in the two extremes of the urban zone, have presented the greatest volume of public investment in municipal origin housing of the last few years given the implementation of several housing estates.

With emphasis on the North region, due to the construction of *Conjunto Habitacional Jacinta Andrade* (Jacinta Andrade Housing Estate) with investments by the Federal Government – the project was managed by *Agência de Desenvolvimento Habitacional do Piauí (ADH)* - (Piauí Housing Development Agency (ADH); it has 4,000 housing units and is located 15Km from downtown Teresina.

Sperandelli, Dupas and Pons (2013) and Nadalin and Igliori (2015) observed "the *peripherization* of poverty", which is linked to urban expansion and to socio-spatial inequality. It is so, because the high prices of areas well-served with infrastructure and the retention of land for speculation, push low-income families to places far from spaces supplied with basic services.

Teresina City has almost 50% of its spaces sealed and it has less than 40% of soil covered with vegetation. Public outdoor spaces (squares, parks, Zoo, the *Centro de Ciências Agrárias da Universidade Federal do Piauí (UFPI)* - Agricultural Sciences Center of Federal University of Piauí (UFPI) -, *Empresa Brasileira de Pesquisa Agropecuária (EMBRAPA)*, and the Botanical Garden) account for 864.8 hectares of the total of 10,046.34 hectares of vegetated soils observed in 2015 (TERESINA, 2013).

The "densification with quality", balance between urbanization and green areas, suggested by Lehmann (2016) and Riffat, Powell and Aydin (2016), as the steps to be taken towards reaching urban sustainability, are realities quite far from Teresina. Table 4 presents data about population density and housing in Teresina in 2000 and 2010.

Table 4 - Population density and housing in Teresina in 2000 and 2010, based on satellite images.

TERESINA	URBAN POPULATION	URBAN HOUSING	URBANIZED SOILS (hectare)	POPULATION DENSITY (inhab./ha)	HOUSING DENSITY (houses/ha)
2000	677,470	162,494	7,003.08	96.74	23.20
2010	767,557	210,270	10,759.68	71.34	19.54

Source: IBGE (2000a; 2010a), TERESINA (2015a), Images LANDSAT 7_TM, USGS (2000; 2010), processed in SPRING and ArcGIS (10.3)

The recorded mean density (29.06 inhab/ha) was quite below that recommended for the efficient infrastructure distribution. According to Mascaró; Mascaró (2001), it must be of at least 40 inhab/ha – estimates show that these data about public outdoor spaces and vegetal coverage recorded for Teresina have pointed towards a more and more spread city, with large areas of sealed soils, and such a scenario brings along doubts about the future of such spaces.

The reduction in net density is another aspect evidencing the spreading process. It refers to the ratio between population data and occupied areas between 2000 and 2010, in

Teresina, based on satellite images. It only included the territorial area occupied by urbanized soils and only took into account the urban population in Teresina. Net densities dropped from 96.74 inhab/ha in 2000 to 71.34 inhab/ha in 2010.

FINAL CONSIDERATIONS

Thinking about urban sustainability implies, among other aspects, reflecting about how a given population uses spaces in a balanced, efficient and accountable way in order to improve them all, nowadays and in the future. Among the sustainability possibilities found in the literature, "densification with quality" would be one of them, according to which, urbanization must walk by densification and by increase in green areas.

Teresina City presents an accelerated urban expansion process, which is more featured as spread than compact. There is much more soil consumption than population growth, and unbalance between sealed and vegetated soils.

With respect to the existing vegetation, a worrisome fact lies on the total of soil vegetation cover: only 10% of the existing vegetation cover is insured as public and under preservation, and it brings uncertainty about the destiny of most of this soil coverage type.

The already consolidated regions in Teresina (Central, South, Southeast and East) have presented urbanized soil growth lower than that of the other ones, which are featured by recent urbanization (North, Northeast and Far South). Urbanized soil growth in consolidated regions was clear in the core areas, whereas the fringes in the other regions recorded the greatest urbanized soil growth. Urban territories among consolidated regions in Teresina were the ones recording the greatest urbanized soil expansion, these territories are located in the East and Southeast regions – the Far South and North regions stand out among regions accounting for the most recent urbanization process.

The East and central regions, which house individuals with the highest income rates, are the areas where one finds spaces presenting the best public-services supply. The other regions, mainly those inhabited by mid- and low-income families (lower than three minimum wages), are featured by precarious access to public services.

The sealing of vast urban soil areas in Teresina, added to the great losses and unequal distribution of its vegetation cover, are indicative of an urbanization process that is not sustainable, since urbanization is not walking by increase in vegetation areas. These aspects are concerning, given the future possibilities set for these soils. These results point out that the legislation in place does not ensure vegetation preservation and use in favor of the city, as a whole, and of its population.

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AUTHOR'S CONTRIBUTION

Silvia Maria Santana Andrade Lima conceived the study, collected, analyzed the data and wrote the text. Wilza Gomes Reis Lopes participated in the elaboration of the study and in the reading, discussion and correction of the text. Antonio Cardoso Façanha collaborated in the reading and discussion of the text.