

Remote sensing applied to the detection of changes in land use and surface temperature in the Mojuí river watershed

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Abstract

The changes resulting from intensive land use, go beyond the changes in the landscape configuration and the availability of natural resources, also affect the physical and biological properties of the soil, and the energy exchange at the surface interface - atmosphere, occurring through the components the radiation balance, the surface temperature highlighting (Ts) that is highly susceptible to the pattern of land occupation. Mojuí River watershed in western Pará, is embedded in a region of diverse uses and land cover, and comes under pressure due to the expansion of mechanized agriculture and the influence of the dynamics surrounding the BR-163 (Cuiabá-Santarém) where much of the forest cover has been degraded. Thus, the purpose of this study is to analyze the dynamics of land use in the basin of Mojuí River and the surface temperature (Ts) by map land use and land cover and Ts, using this algorithm the SEBAL (Surface Energy Balance Algorithm for Land) and satellite images Landsat 5 - TM, corresponding to the days 02/08/1999 and 29/06/2010, processed in SPRING software. The results showed that the introduction of mechanized agriculture in the region significantly changed the local landscape as well as the expansion of the urban area of the municipality studied. It contacted even if, in addition to changes imposed on vegetation, human activities have caused an imbalance in surface temperature, which showed more areas with higher temperature values due to the increase of areas with exposed soil.

Keywords: use of land, surface temperature, Mojuí River, SEBAL, LANDSAT.

1. Introduction

In recent decades, many changes and transformations in the spatial pattern of land use and cover in the national territory have been occurring intensively. These transformations, natural or anthropogenic, have changed not only the landscape pattern but also the processes and the availability of resources that are involved, inextricably, to the type of surface coverage, as well as socio-economic dynamics from activities resulting from changes of land use.

Among the activities that contribute most to these is agriculture, livestock and urban sprawl. According to Nepstad et al. (2002) cultivated areas, grasslands and urban areas, cover approximately 35% (about 55 million square kilometers) of continental surfaces.

As a result of changes in land use, physical and biological properties of the surface are affected, causing a series of impacts on the environment such as: soil erosion, which increases the amount of drainage and reduce the soil protection; the loss of biodiversity, which threatens the existence of many animal and vegetal species; and siltation of rivers and lakes. Moreover, these changes also alter the energy exchanges between the surface and the atmosphere, which occur through the components of the radiation balance. The albedo, of the radiative properties of the surface, is severely altered, which can significantly affect water and energy exchanges (Nobre et al., 1991; Gioli et al., 2004; Yanagi and Costa, 2011; Cunha et al., 2013). Another important parameter that changes is the Temperature of the Surface (Ts) that according to Hashimoto et al. (2003) is highly susceptible to the pattern of land occupation.

Several studies have been conducted in the Amazon region to identify impacts on climate occurred with changes in land use in areas converted primarily to grasslands and agricultural crops (Malhi et al., 2008; Oliveira, 2008; Machado 2012), more specifically related to biogeochemical and biogeophysical properties. According to Nobre et al. (2009), the Amazon forest plays an important role in regional and global climate, acting as one of the global sources of water vapor

and therefore, of latent heat; the evaporated water to the surface is transported to the upper troposphere by intense tropical convection, and from there, it contributes with energy to move the global atmospheric circulation. Thus, changes in land use in this environment can cause impacts on atmospheric circulation, the humidity transport to and from the region and, consequently, the water cycle, not only over South America, but in other parts of the world (Correia et al., 2007).

In this context, Mojuí River watershed is inserted in a region of diverse land uses and cover, and has come under pressure due to the expansion of mechanized agriculture. In addition, is influenced by the dynamics surrounding the BR-163 (Santarém-Cuiabá), located in western Pará, a region which has undergone enormous changes in the landscape, in addition to a growing population and urban sprawl increase.

For the identification and quantification of these changes, the use of satellite images proved to be an important tool, and is increasingly being adopted by scholars and federal agencies monitoring forest cover, especially in the Amazon environment. As highlights Rosendo (2005), the use of satellite imagery for surface monitoring is a very effective resource, because it has important features such as: speed, which allows obtaining information in a short time span; repeatability, which helps to compare both the area as the imaged target conditions and an overview of the study area, allowing to obtain information about large areas in single outlet data. They facilitate the understanding of the complex relationship between the various environmental phenomena in various temporal and spatial scales, being an effective way to collect environmental data (Souza, 2010).

In the scope of the discussion, the present work was developed with the goal to analyze the dynamics of land use in the Mojuí River watershed and the Temperature of the Surface (Ts) by map of land use and land cover and of the Ts, using images of the Landsat TM5 satellite during the years of 1999 and 2010.

2. Materials and methods

2.1 Location of the study area

Mojuí River watershed is located in the city of Mojuí dos Campos, which is 34 km away from the urban seat of the city of Santarém, with its location between the Latitude 2 ° 40 '26.1516 "S and Longitude 54 ° 38 '53.7103 "W (Figure 1).

Mojuí River watershed goes beyond the limits of the city of Mojuí dos Campos, entering the municipal territories of Santarém and Belterra, both situated on the Santarém Plateau, in the Western Pará State.

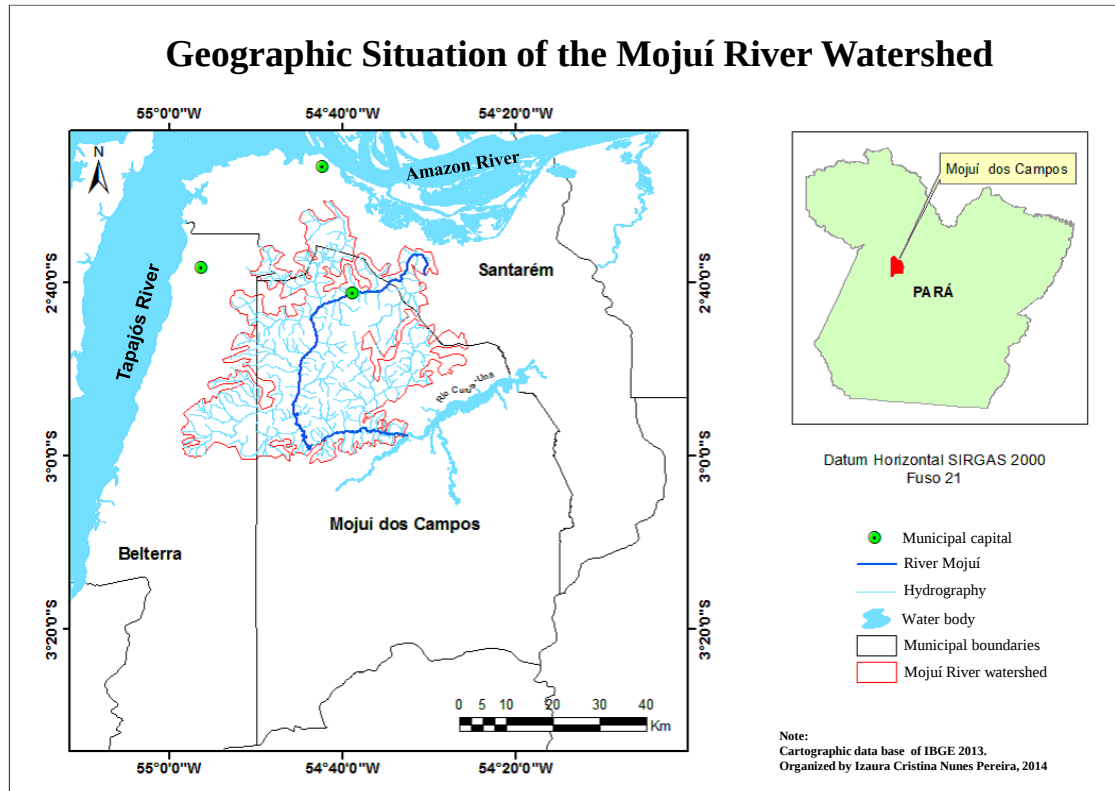


Figure 1 - Location of the study area. Source: Pereira (2014).

According to IBGE (Brazilian Institute of Geography and Statistics) (2008), the predominant type of soil within the basin is the Dystrophic Yellow Latosol. As for geomorphology, it integrates the morphostructural unit Basins and Phanerozoic sedimentary covers, whose unit is defined as the Tapajós levels.

Understanding the dynamics intrinsic to the basin research moves through the recognition of the spatial context in which it is inserted, in this case the city of Mojuí dos Campos and changes in land use and cover over the years.

2.2 Methodology

To assure the development of the work, initially it was performed a data and information

collection about Mojuí River watershed. It is noteworthy that parallel theoretical-conceptual review about the subject watershed and changes in land use and land cover was performed.

In the following stage, it was performed the delimitation of the area of the basin in question. For this, it was used Geoprocessing (GIS) techniques in ArcGIS environment 10.2, Remote Sensing in SPRING, cartographic data and scenes Landsat TM5 of the area of interest.

First, it was performed the delimitation of the area of the basin in question, which was made possible by using the supervised method from the contour lines and elevation points, available in the Sheet SA-21-ZB-II from the Army Geographical Service Board (DSG) the scale of 1: 100,000.

After defining the limits of the basin, the following stage was the its clipping to the scenes Landsat TM 5 orbit / point 227/62, obtained without charge at the website of the National Institute for Space Research (INPE). After the processing, the area of the basin was cropped for further classification and generation of land use and cover map. Through this byproduct, it was possible to visualize and quantify the representation in areas of the main land uses and cover in the basin in question.

2.3 Satellite images processing

For this analysis, two scenes from the Landsat-5 TM sensor were used, freely distributed by INPE, through its Imaging Generation Division (DGI) (NATIONAL INSTITUTE RESEARCH SPACE, 2012). The scenes correspond to orbits/points 227/62 covering the entire basin, corresponding to the satellite passage dates from the days August 2, 1999 (Julian Day 215) and June 29, 2010 (Julian Day 150), in the bands 3, 4 and 5 for the generation of thematic map of use and coverage and Thermal Image (band 6) for the surface temperature.

The scenes were chosen according to the cloud cover percentage on the scene, considering the difficulty of obtaining images with this feature in a tropical region (Corrêa et al., 2011), while maintaining a multitemporal difference for analytical change of land use.

In the pre-processing stage, the scenes were recorded in SPRING. After the record, it was performed the radiometric correction corresponding to the conversion of digital numbers (DN) for apparent reflectance values. The reflectance values were performed by LEGAL (Spatial Language for Algebraic Geoprocessing) SPRING, using the calibration parameters obtained in the header of LANDSAT images.

For the analysis of landscape change in the time frame mentioned, it was applied the unsupervised digital classification technique from the segmented images. The classification is a technique that allows the identification of homogeneous patterns and objects on the Earth's surface, as well as the quantification of these standards and, consequently, of the

transformations in the landscape. The product classification enabled the construction of the dynamic of the basin.

To facilitate the visual contrast of the target's spectral response in the generated product, four thematic classes were considered (Water, Forest Cover, Secondary Vegetation and Anthropic Use). In the case of Anthropic Use class, agricultural areas, bare soil and urban sprawl are included.

To obtain the surface temperature, the SEBAL algorithm was used throughout the implementation of the steps described below (Figure 2):

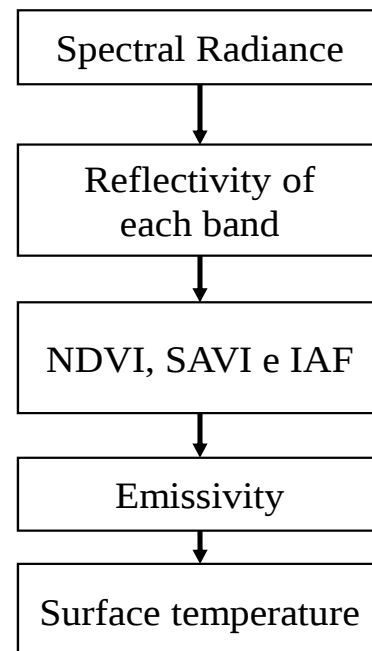


Figure 2 - Methodology flowchart of the steps for obtaining the surface temperature through the SEBAL algorithm.

Step 1 – Spectral Radiance

In this step, the Digital Number (DN) of each pixel of the image is converted into monochromatic spectral radiance, representing the solar energy reflected by each pixel, per unit area, per time, per solid angle and per wavelength, measured at the level of satellite TM - Landsat 5, according to the equation proposed by Markham and Baker (1987):

$$L_{\lambda i} = a_i + \frac{b_i - a_i}{255} \times ND \quad 01$$

in which, $L_{\lambda i}$ is the spectral radiance of each band, and b are the minimum and maximum spectral radiance ($W m^{-2} sr^{-1} \mu m^{-1}$, Table 1); ND is the

pixel intensity (digital number, integer from 0 to 255); i are the bands (1,2,3,4,5,6,7) of satellite TM - Landsat 5.

Table 1 - Description of the bands of the Thematic Mapper (TM) of Landsat 5, with the corresponding wavelength ranges, calibration coefficients (minimum radiance - a; and maximum - b) and spectral irradiances at the top of the atmosphere (TOA).

Bands	Wavelength (μm)	Calibration Coefficients ($Wm^{-2}sr^{-1}\mu m^{-1}$) After May 5, 2003		Spectral Irradiances at the top of the atmosphere ($Wm^{-2}\mu m^{-1}$)
		a (Lmin)	b (Lmáx)	
1 visible (blue)	0,45 – 0,52	-1,52	193,0	1957
2 visible (green)	0,52 – 0,60	-2,84	365,0	1829
3 visible (red)	0,63 – 0,69	-1,17	264,0	1557
4 (IV- near infrared)	0,77 – 0,90	-1,51	221,0	1047
5 (IV- short – wave infrared)	1,55 – 1,75	-0,37	30,2	219,3
6 (IV-thermal infrared)	10,40 – 12,50	1,2378	15,303	-
7 (IV- short - wave infrared)	2,09 – 2,35	-0,15	16,5	74,52

Source: <http://landsat.usgs.gov>

Step 2 - Reflectance

The second step consists in obtaining the monochromatic reflectance of each $\rho_{\lambda i}$ band through the ratio between the solar radiation reflected by the surface and the incident solar radiation flux, obtained by the equation:

$$\rho_{\lambda} = \frac{\pi \cdot L_{\lambda}}{ESUN_{\lambda} \cdot \cos \theta \cdot d_r^2} \quad 02$$

Where:

L_{λ} is the spectral radiance for each band compute in equation 01, $ESUN_{\lambda}$ is the mean solar exo-atmospheric irradiance for each band ($W/m^2/\mu m$), $\cos \theta$ is the cosine of the solar incidence angle, and d_r is the inverse squared relative earth-sun distance. Values for $ESUN_{\lambda}$ are given in Table 2.

Step 3 - Albedo at the Top of the Atmosphere

The albedo at the Top of the Atmosphere is the surface albedo in the field of short-wave radiation (0,3 – 3,0 μm), but without atmospheric correction, obtained through linear combination of

monochromatic spectral reflectance of reflective channels of Landsat- 5 TM:

$$\alpha_{toa} = 0,293\rho_1 + 0,274\rho_2 + 0,233\rho_3 + 0,157\rho_4 + 0,033\rho_5 + 0,011\rho_7$$

Where; α_{toa} is the planetary albedo; ρ_1 , ρ_2 , ρ_3 , ρ_4 , ρ_5 , ρ_7 are monochromatic reflectance of bands 1, 2, 3, 4, 5 and 7.

Table 2- Solar Spectral Irradiances ($ESUN_{\lambda}$)

Band	watts/ (meter squared * μm)
1	1969.000
2	1840.000
3	1551.000
4	1044.000
5	225.700
7	82.07
8	1368.000

Step 4 - Albedo at the surface

After obtaining the albedo at the top of the atmosphere it was made the calculation of the surface albedo (α) or albedo corrected for atmospheric effects by the equation:

$$\alpha = \frac{\alpha_{toa} - \alpha_p}{\tau_{sw}^2} \quad 04$$

Where; α is the average portion of the incoming solar radiation across all bands that is back-scattered to the satellite before it reaches the earth's surface, and τ_{sw} is the atmospheric transmissivity. To calculate τ_{sw} assuming clear sky and relatively dry conditions using an elevation-based relationship:

$$\tau_{sw} = 0,75 + 2 \cdot 10^{-5} \cdot z \quad 05$$

Where; z is the elevation above sea level (m) of the city Mojuí dos Campos.

Step 5 - Vegetation indices: NDVI, SAVI and LAI

The Normalized Difference Vegetation Index (NDVI) is a measure of the amount and vigor of vegetation at the surface. The reason NDVI is related to vegetation is that healthy vegetation reflects very well in the near infrared part of the spectrum. Green leaves have a reflectance of 20 % or less in the 0.5 to 0.7 range (green to red) and about 60 percent in the 0.7 to 1.3 μm range (near infrared). The value is then normalized to $-1 \leq \text{NDVI} \leq 1$ to partially account for differences in illumination and surface slope. The index is defined by equation 6.

$$\text{NDVI} = \frac{\rho_{IV} - \rho_V}{\rho_{IV} + \rho_V} \quad 06$$

Where; ρ_{IV} and ρ_V correspond to bands 4 and 3 of Landsat 5 - TM.

The SAVI is a vegetation index that aims to reduce the effects of "background" of the soil, being obtained through the equation: (Huete, 1988):

$$\text{SAVI} = \frac{(1 + L)(\rho_{IV} - \rho_V)}{(L + \rho_{IV} + \rho_V)} \quad 07$$

Where; L is a adjustment factor.

The leaf area index LAI represents the total biomass and is indicative of crop yield, canopy resistance and heat flux. The LAI is defined as the ratio of the total area of all leaves on a plant to the ground area covered by the plant. The computation of the IAF, which is the ratio between the total area of all the leaves contained in a given pixel

and the pixel area, is done through the equation:

$$\text{IAF} = - \frac{\ln\left(\frac{0,69 - \text{SAVI}}{0,59}\right)}{0,91} \quad 08$$

Step 6 - Surface Emissivity

For the purposes of calculating the Temperature of the Surface (T_s) and the long-wave radiation emitted by the surface, it is necessary to estimate the spectral emissivity in the field of thermal band (ϵ_{NB}), obtained by the expressions:

$$\epsilon_{NB} = 0,97 + 0,00331 \cdot \text{IAF} \quad 09$$

$$\epsilon_0 = 0,95 + 0,01 \cdot \text{IAF} \quad 10$$

For pixels with $\text{IAF} \geq 3$, $\epsilon_{NB} = \epsilon_0 = 0.98$ and for pixels with $\text{NDVI} > 0$ and $\text{IAF} < 3$, use the equations 9 and 10.

Step 7 - Temperature of the Surface - T_s

The temperature of the surface is obtained through reversed Planck equation, depending on the spectral radiance of the thermal strip ($L_{\lambda,6}$) and emissivity ϵ_{NB} , according to the equation:

$$T_s = \frac{K_2}{\ln\left(\frac{\epsilon_{NB} K_1}{L_{\lambda,6}} + 1\right)} \quad 11$$

Where; $K_1 = 607,8 \text{ Wm}^{-2}\text{sr}^{-1}\text{m}^{-1}$ and $K_2 = 1261\text{K}$.

3. Results and discussion

Land use and occupation in the Mojuí River watershed

Within the basin is possible to evaluate how the land use and cover is distributed among the studied dates, and through this analysis we can clearly see that although the vegetation cover is large along the basin, it does not mean that it remains unchanged, since much of the forest cover has been gradually replaced by new forms of land use, a fact that is due to the intensification of anthropogenic activities in this region.

As shown in Figure 3, in 1999 the basin had in extent large areas of forest cover and secondary vegetation, while presenting small areas with anthropogenic use.

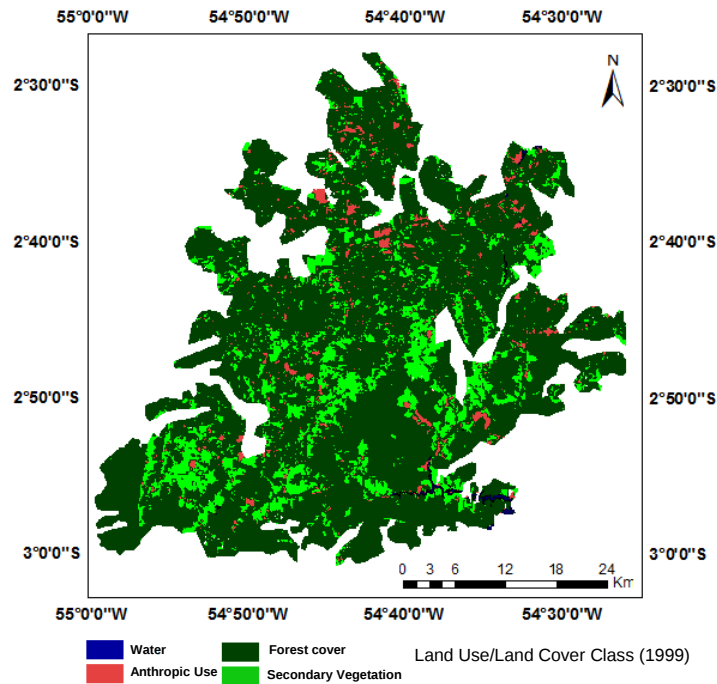


Figure 3 - Land use and land cover of Mojuí River watershed in 1999.

However in 2010 there was an increase of anthropic use areas over the primary forest areas (Figure 4). According to the history of occupation of the basin in question, the grain

mechanized agriculture activity, especially of soybeans, is the main responsible for the series of transformations in the landscape of the region (Borges and Pereira, 2014).

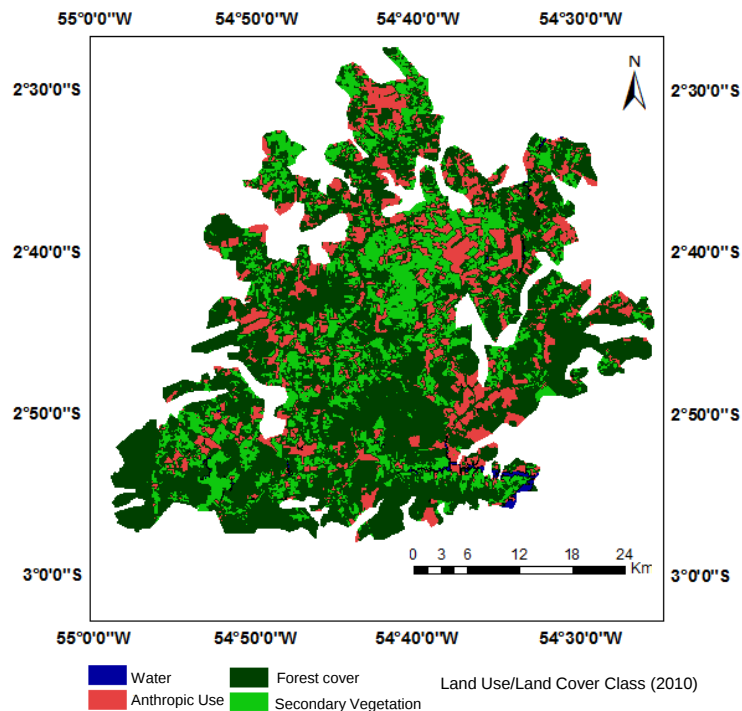
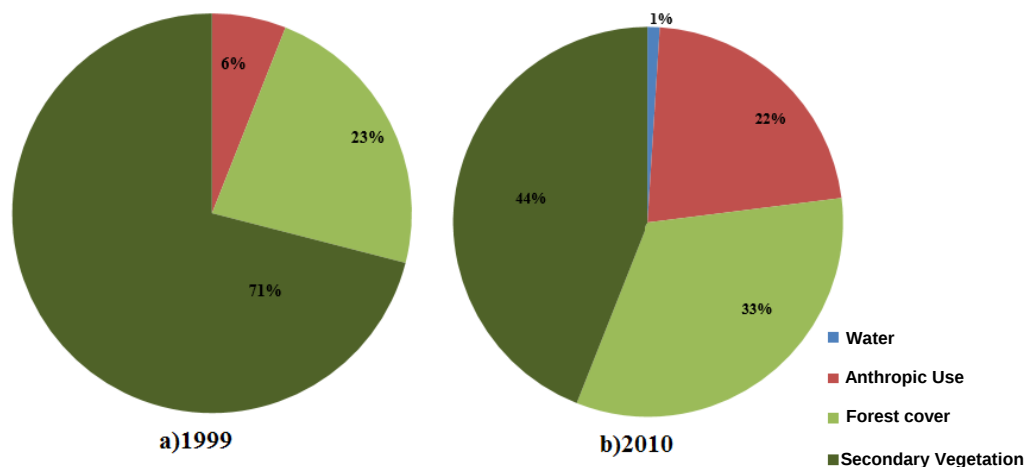


Figure 4 - Land use and coverage of Mojuí River watershed in 2010.

The decrease of primary forest areas is a consequence of a rapid and accelerated expansion of agribusiness, which has occurred since the late 1990s on the Santarém Plateau, region in which Mojuí River watershed is located. Moreover, factors such as the newly installed city of Mojuí dos Campos lying around the basin, which is still through the phase of economic and population development, as well as the enhancement and creation of roads for the outflow of Agricultural production, contribute to this problematic. Flexor et al. (2006) also highlight that the expansion of soybean cultivation in the Santarém region has motivated small farmers, who are under great pressure due to the appreciation and enhancement of land, leading these groups to leave their old areas and take refuge on the periphery of the regional urban centers, or in other cases to put

pressure on new forest areas, resulting on new deforestation processes.

In Graphic 1, we can observe how divided are the classes of use of Mojuí River watershed - PA, in which one can observe that in 1999, the forest cover percentage was 71%, and in 2010 decreased to 44%. It was observed that in areas previously occupied by the forest class passed to anthropogenic or secondary vegetation use over the 12 years of analysis. The secondary vegetation class showed a 10% increase in 2010 compared to 1999, which demonstrates that the areas covered by secondary vegetation are expanding into areas which were originally occupied by a primary forest or utilized for other types of land use, in a stage of recovery from heavy agricultural use. As for anthropogenic use in the period 1999 to 2010, it presented an increase of 16%.



Graphic 1 - Classes in the Basin of Rio Mojuí - PA for the years 1999 (a) and 2010 (b).

Surface Temperature Distribution in the Basin

The Figure 5 shows the distribution of surface temperature of Mojuí River watershed on August 2nd 1999. It is noted that the highest temperatures are between 30 and 32 ° C and in areas that, according to the map of land use and cover, is anthropogenic use. The lowest surface temperatures, captured by satellite, have a minimum of 21 ° C, and are located in forested areas, namely, on a stretch of the Tapajós National Forest which is within the limits of the basin (southwest of the basin, near BR 163), places

which are near the Curuá-Una Power Plant, located southeast, and small spots distributed throughout the basin. It is important to note that, during this period, the perimeter of the city hall of Mojuí dos Campos showed increasing expansion of the urban core and its population, even though it still belonged to the city of Santarém, being fully emancipated only in 2009. Despite being through an expansion process, the level of urbanization and bare soil areas were low when compared to 2010, which may explain the low temperatures found in a large part of the scene.

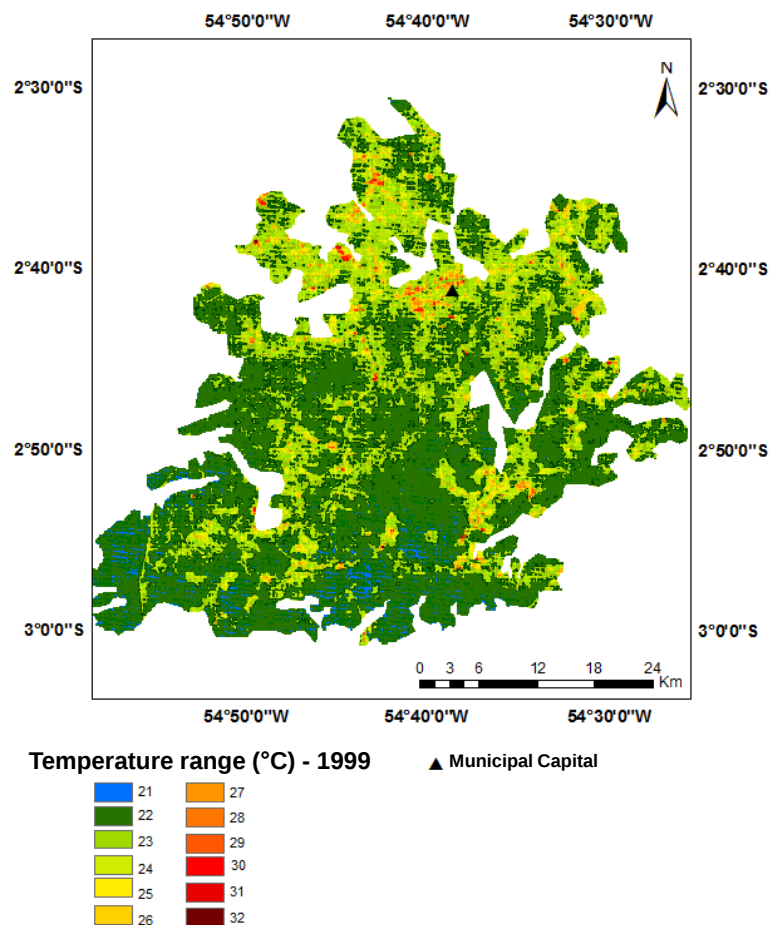


Figure 5 - Distribution of Surface Temperature in Mojuí River watershed on August 2nd, 1999.

The spacialization of the surface temperature on June 29th, 2010, according to Figure 6, shows a temperature variation with a minimum of 17 ° C and maximum 30 ° C to the basin area. It is noted that the highest temperatures are in areas classified as of anthropogenic use. Those areas have experienced an increase of 10% compared to 1999.

In the northern part of the scene (Figure 6), we can see that the temperatures are higher compared to the southern part, because in this area there are large areas of exposed soil, from the practice of agriculture, the main activity in the region, as shown in Figures 3 and 4. The changes in land use, mainly the conversion of areas covered by dense vegetation to types of use that expose the soil to solar radiation, contribute to the elevation of the surface temperature, because the soil is more exposed and undergoes heating, thus the

components of the energy balance and the air temperature near the ground can be altered.

Thus it can be seen that the changes in the typical landscape of the region in recent years may be causing a change in the apparent surface temperature values, as can be seen in Figures 5 and 6, in which there was an increase of areas with temperature values of 28 to 30 ° C, in which prior to that were covered with soil and had temperatures from 22 to 25 ° C.

Through the exchange from forest cover to anthropogenic use, there was an increase of areas with temperature elevation, indicating that the increase of those areas was caused, among other factors, mainly by a change in the intensity of land use, a fact which can cause in the medium and long term an imbalance in the microclimate of the region such as the appearance of phenomena such as heat islands.

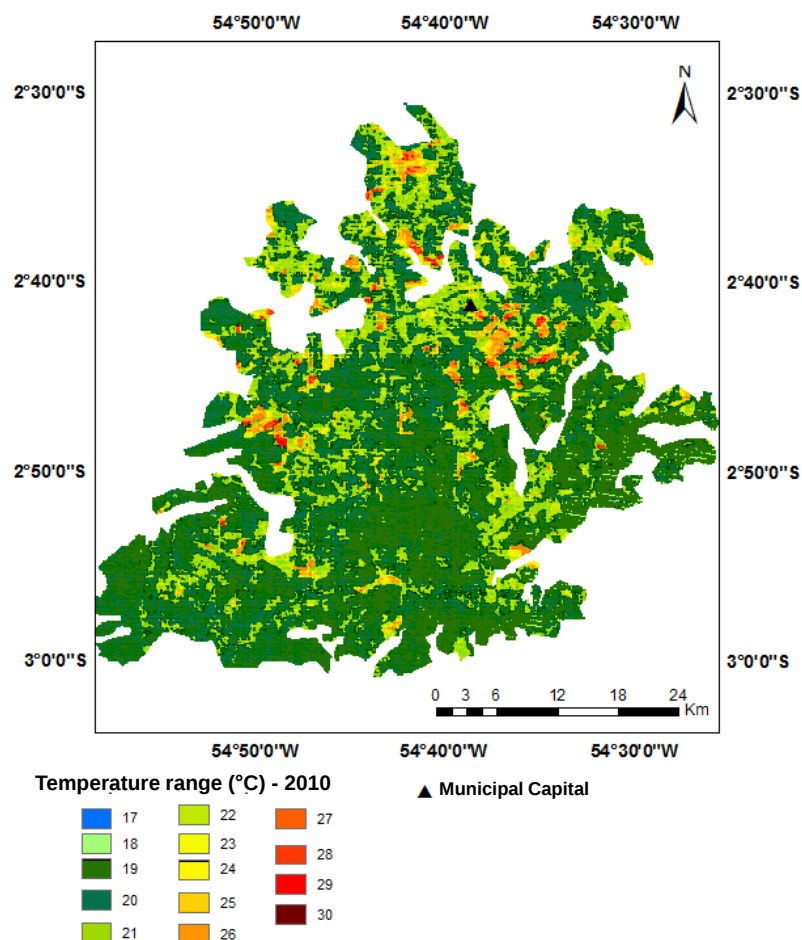


Figure 6 - Surface Temperature Distribution in Mojuí River watershed on June 29th, 2010.

4. Conclusions

From the satellite images it was possible to analyze the changes that have occurred in land use and land cover in the city of Mojuí dos Campos - of the given city, significantly changed the local landscape.

It was also noted that in addition to the changes imposed on the vegetation cover, the anthropogenic activities have caused an imbalance in surface temperature, which showed more areas with higher temperature values due to the increase of areas with exposed soil.

The pace of the change in land use and land cover in Mojuí River watershed warns about the need for greater control in the process of development of economic activities, especially the ones of large environmental impact, such as

PA in 1999 and 2010. It can be noted that the introduction of mechanized agriculture in the region, as well as the expansion of the urban area mechanized agriculture, although this is the main economic source the city in which the basin in question is located. Linked to this is the process of urban expansion of the city core, as already stressed, that follows in a disorderly manner and towards the main water bodies of the city.

It should be also noted that in a microscale, the identified changes may alter the surface energy balance through its components including the soil temperature which may be presented higher in modified coverage than in primitive coverage. In addition, it changes the rainfall, causing the emergence or intensification of hotspots

It is noteworthy that despite this study being still exploratory mainly due to satellite imagery used for the surface temperature representing only a moment of the scene, the findings here presented are sufficiently encouraging for more detailed analysis of the long and medium term impacts in the change of land use in the phenomena of meso and micro scale in the climate of the region.

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