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Spatial-Temporal Monitoring of the Risk of Environmental Degradation and Desertification by Remote Sensing in a Brazilian Semiarid Region

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ABSTRACT

The Brazilian semiarid region lacks constant environmental monitoring of the soil uses, to apply reversion and prevention measures over hydric and natural resources in the long and medium-term. Remote sensing enables advances and essential conditions to efficiently monitor changes caused in the vegetation dynamics of the Caatinga biome. Thus, the objective was to monitor and assess the risk of environmental degradation and desertification, using geoprocessing together with remote sensing techniques, highlighting the analysis of the landscape pattern and Spatial-temporal modeling of micrometeorological biophysical parameters using satellite images and surface meteorological data for the semiarid region of Iguatu, Ceará, Brazil. Thematic maps of the albedo and surface temperature and the risk of degradation of the region were developed, evaluated by descriptive statistics, precision measures and thematic quality. The areas of exposed soil, with little vegetation cover and urban area, expressed the highest values of albedo (0.21 to 0.45) and surface temperature (23.20 to 47.00 °C), which are more susceptible to processes of local environmental degradation. Deficits in precipitation, drought and the gradual increase in temperature in the semiarid region, over time, accentuated the risk of degradation, with percentage increases of up to 51.96% (high), 23.79% (severe) and 17.56% (moderate) of the total area of the region. It is concluded that the rules established by decision tree and use of micrometeorological indicators allowed to quantify and monitor the risk of environmental degradation in space and time, with an assessment of precision and excellent thematic quality.

Keywords: geoprocessing, Caatinga, deforestation, biophysical parameters, agrometeorology.

Monitoramento Espaço-Temporal do Risco de Degradação Ambiental e Desertificação por Sensoriamento Remoto em Região Semiárida Brasileira

RESUMO

O semiárido brasileiro carece de um monitoramento ambiental constante dos usos do solo, para aplicação de medidas de reversão e prevenção sobre os recursos hídricos e naturais à longo e médio prazo. O sensoriamento remoto viabiliza avanços e condições essenciais para monitorar mudanças causadas na dinâmica da cobertura vegetal do bioma Caatinga, de forma eficiente. Com isso, objetivou-se monitorar e avaliar o risco de degradação ambiental e desertificação, utilizando geoprocessamento junto as técnicas de sensoriamento remoto, destacando as análises do padrão de paisagem e modelagem espaço-temporal de parâmetros biofísicos micrometeorológicos a partir do uso de imagens de satélite e dados meteorológicos de superfície para a região semiárida de Iguatu, Ceará, semiárido brasileiro. Foram desenvolvidos mapas temáticos do albedo e temperatura da superfície e do risco de degradação da região, avaliados por estatística descritiva, medidas de precisão e qualidade temática. As áreas de solo exposto, de pouca cobertura vegetal e área urbana expressaram os maiores valores de albedo (0,21 a 0,45) e temperatura da superfície (23,20 a 47,00 °C), sendo estas mais susceptíveis aos processos de degradação

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ambiental local. Os déficits de precipitação, a seca e o gradativo aumento da temperatura na região semiárida, ao longo do tempo, acentuaram o risco de degradação, com percentuais de aumento de até 51,96% (alta), 23,79% (severa) e 17,56% (moderada) da área total da região. Conclui-se que as regras preestabelecidas por árvore de decisão e uso de indicadores micrometeorológicos permitiram quantificar e monitorar o risco de degradação ambiental no espaço e no tempo, com avaliação de precisão e qualidade temática excelente.

Palavras-chave: geoprocessamento, Caatinga, desmatamento, parâmetros biofísicos, agrometeorologia.

Introduction

The semiarid climate is present in several locations around the world (North America, South America, Africa, Europe, Asia, and Oceania) and is characterized by low/seasonal rainfall rates with interannual variability, low humidity, and high temperatures, and besides, soils in these locations generally have low fertility, which the sum of all these factors limit the development of agriculture (D'Odorico et al., 2013; Brandt et al., 2014; Mariano et al., 2018).

In addition to the problems of water scarcity, climate change, and droughts, the lack of detailed studies and environmental monitoring in the main biomes of the semiarid regions, such as the Caatinga (characteristic of the Brazilian semiarid region) makes it impossible to understand the scope of the changes and/or changes semiarid climate and also the possible impacts generated by anthropic actions (deforestation, soil erosion, forest fires, intensive agricultural practices, inadequate use of irrigation water, etc.) that contribute to the worsening of environmental degradation, expanding the exposed soil areas and consequently the high desertification of agricultural areas and the impoverishment of the region (Hastenrath, 2012; Palácio et al., 2013; Gutiérrez et al., 2014; Marengo et al., 2016; Marengo et al., 2018; Mariano et al., 2018).

Several studies involving remote sensing usually assess and monitor the risk of degradation and desertification, characterized mainly by the change in vegetation biomass, landscape pattern and micrometeorological conditions, based on important indicators for detecting changes in the soil surface of semiarid regions, highlighting the biophysical parameters albedo and surface temperature, as well as the Soil Adjusted Vegetation Index (SAVI), which is important for mitigating the antecedent effects of the soil, considering from the adjustment factor limitations imposed by other vegetation indexes in the Brazilian semiarid, giving reliability to the information on the different uses of the Caatinga soil and vegetation in the regions (Xu et al., 2009; Arraes et al., 2012; Silva and Galvêncio, 2012; Bezerra et al.,

2014; Vorovencii, 2015; Ribeiro et al., 2016; Silva et al., 2019).

This study brings as main innovation, the semiarid regions of Brazil, in addition to the quantification of micrometeorological biophysical parameters of the Earth's surface, the creation of maps of the risk of environmental degradation in different degrees, using satellite images to propose new techniques for environmental monitoring subsidized by indicators that express the Spatial-temporal heterogeneity of the Caatinga biome, with high precision and on a large scale, with remote sensing being a promising tool to facilitate management in decision making to achieve sustainability in the use of hydric and natural resources, aiming mainly the protection and conservation of the remnants of natural Caatinga vegetation (Xu et al., 2009; Arraes et al., 2012; Giongo and Vettorazzi, 2014; Zheng et al., 2016; Silva et al., 2019).

Given this context, the objective was to monitor and assess the risk of environmental degradation and desertification in a semiarid region of Northeast Brazil, using geoprocessing together with remote sensing techniques, highlighting the analysis of the landscape pattern and Spatial-temporal modeling of components of the energy balance, using satellite images and surface meteorological data, in the period from 2008 to 2015.

Material and methods

Characterization of the study area

The study area, which is the municipality of Iguatu, is located in the Brazilian semiarid region, more specifically, in the central-southern mesoregion of the state of Ceará, Northeast Region of Brazil, located in the coordinates between the parallels of 6° 11' 31.78" S (UTM: 9315534 m) and 6° 34' 9.76" S (UTM: 9273854 m), and between the 39° 3' 36.52" W meridians (UTM: 493351 m) and 39° 25' 54.33" W (UTM: 452234 m), altitude 217.8 m. According to the Köppen classification, the study area belongs to the BSw'h' climatic zone (hot and semiarid climate),

characterized by presenting an annual average air temperature of 26 to 28 °C (Alvares et al., 2013).

The rains show temporal and spatial irregularities, with a total annual average of 817.91 mm referring to the historical series of climatological data of 30 years, between 1989-2018 - pluviometry station of the National Water Agency (ANA), code: 00639044, located in geographical coordinates of 6° 22' 27.4" S (UTM: 9295412 m) and 39° 17' 35.9" W (UTM: 467563 m) (ANA, 2019). The region has two well-defined seasons during the year, that is namely

rainy and dry. The rainy season runs from January to April. The dry season can last from 7 to 8 months and present high temperatures that cause high evaporation (Arraes et al., 2009; IPECE, 2017).

Figure 1 shows the spatial map of the location of the study area in composition in bands 5 (R) 4 (G) 3 (B), with a spatial resolution of 30 m, highlighting the cover and soil use of the region from an image orbit of the Landsat-8 satellite from the OLI sensor on August 24, 2015.

Figure 1. Spatial map of the location of the study area, municipality of Iguatu, Ceará, Brazil.

The study area has an area of 1029.2 km², the predominant vegetation is the shrub dense Caatinga and soils Alluvials, Litolics, reds-yellow Podzolics and Vertisols (IPECE, 2017). The areas expressed in the Municipality map in red color, the cultivation of irrigated agriculture, in dark blue and black, the bodies of water of the reservoirs are observed, areas with a predominance of thin and dense Caatinga vegetation are also present. Also noteworthy are the points of the location of the city and the automatic

meteorological station responsible for the registration of surface data (Figure 1).

Surface weather data

The surface meteorological variables were the average air temperature (T_{air} , °C), relative air humidity (RH, %), atmospheric air pressure (P_o , kPa) and accumulated rainfall (mm) in the 20 days before the passage of the satellites, both data recorded by the weather station located in the study area itself (Iguatu-A319; OMM code: 81873) (Table 1) at the following coordinates of 6° 23' 47" S (UTM:

9292970 m) and 39° 16' 8" W (UTM: 470264 m) and altitude of 233 m, belonging to the National Institute of Meteorology (INMET) (Figure 1).

Table 1. Surface meteorological data recorded during the passage of satellites.

Date of passage	T _{air} (°C)	RH (%)	P _o (kPa)	Precipitation (mm)
09/21/2008	30.2	35.0	98.99	0.0
06/20/2009	26.8	62.0	98.98	14.2
08/29/2011	29.8	37.0	99.08	9.8
09/03/2013	30.3	40.0	98.92	6.4
09/22/2014	31.9	44.0	98.85	8.2
08/24/2015	30.3	36.0	98.90	0.0

Table 2 shows the temporal variability of rainfall recorded by the INMET meteorological station, to obtain more precise details of possible

environmental changes in different soil uses during the region's dry season.

Table 2. Monthly rainfall in the semiarid region during the study period.

Month	Monthly rainfall (mm)					
	2008	2009	2011	2013	2014	2015
January	181.4	159.4	220.0	78.6	60.0	24.6
February	230.0	186.8	263.8	54.2	144.0	142.2
March	456.8	115.2	103.6	72.0	256.8	144.8
April	369.4	380.8	424.0	123.8	219.4	72.0
May	119.0	128.6	125.4	233.0	66.0	113.0
June	1.4	14.4	10.6	88.8	25.6	3.4
July	11.2	34.4	72.4	52.4	25.0	2.4
August	21.0	56.4	10.6	6.4	0.0	0.6
September	0.0	3.2	0.0	1.2	8.2	0.2
October	0.6	0.3	81.2	39.6	44.0	0.0
November	0.0	0.0	14.8	3.2	12.6	0.0
December	7.2	8.5	9.2	27.4	5.6	23.2
Total (mm)	1392.8	1079.2	1335.6	649.8	867.2	526.2

Orbital data

The study was developed from three orbital images from the TM sensor Landsat-5 satellites and three Landsat-8 images from OLI / TIRS sensors, in orbit 217 and point 64. The images were acquired from the spatial database of the National Aeronautics and Space Administration/United States Geological Survey (NASA/USGS). It is noteworthy that all images were chosen to have as the main criterion the least or no clouds, and from the same season, being for the present research the dry season of the semiarid region. The lowest percentage of clouds avoids overestimating or underestimating the results of biophysical parameters, even in small areas.

Table 3 presents information about the images, such as dates and times of satellite passages in the study location, initial input variables for

processing satellite images, such as the square of the ratio between the average and instantaneous distances between the Earth and the Sun (d_r) on a given day of the year envisaged, solar zenith angle (θ), atmospheric transmissivity at the instant of the satellite's passage (τ_{sw}) and the instantaneous atmospheric emissivity of the air (ϵ_a). These initial elements were found from complementary surface data and information observed in the image files provided by USGS/NASA.

Table 3. Input variables for the processing of orbital images at the instant of the satellite passages in the study area.

Satellite	Date of passage	Hour of passage	d_r	θ	τ_{sw}	ϵ_a
Landsat-5 TM sensor	09/21/2008	09h32min	0.995	0.863	0.751	0.759
	06/20/2009	09h36min	0.968	0.742	0.717	0.770
	08/29/2011	09h36min	0.982	0.826	0.745	0.761
Landsat-8 OLI / TIRS sensors	09/03/2013	09h49min	0.983	0.866	0.746	0.761
	09/22/2014	09h47min	0.992	0.895	0.742	0.762
	08/24/2015	09h47min	0.978	0.839	0.747	0.760

The satellite information was extracted through digital image processing performed by mathematical operations using the SEBAL algorithm, an iterative numerical procedure based on multispectral bands 1 to 7, including the thermal band (6) of the Landsat-5 TM, and the multispectral bands from 2 to 7, as well as the thermal band (10) of Landsat-8 OLI/TIRS. The bands were stacked and, georeferenced in the UTM Cartographic Projection System, DATUM: WGS84 - Zona 24 M.

Digital processing of satellite images (SEBAL)

The SEBAL methodology was described according to Bastiaanssen (2000) and Allen et al. (2002). In the algorithm, mathematical processing operations were developed, to estimate components of the energy balance of the Earth's surface, such as albedo and surface temperature, vegetation indices and thematic maps of the risk of degradation in the semiarid region (Bastiaanssen, 2000; Allen et al., 2002; Silva et al., 2019). The determination of spectral radiance and monochromatic reflectance in

each band of Landsat-5 TM and Landsat-8 OLI followed the procedures of Chander et al. (2009) and Silva et al. (2016), respectively.

Tables 4 and 5 highlight the calibration coefficients for the study area, converting gray levels into spectral radiance and monochromatic reflectance, for each of the multispectral bands in the Landsat-5 TM and Landsat-8 OLI/TIRS satellite images.

Table 4 shows the calibration coefficients of minimum (L_{min}) and maximum (L_{max}) radiance, referring to the time of the images in the present study, which is from the period after April 2007 for each spectral band (blue; green; red; Near-Infrared; Short-wave Infrared and Thermal Infrared). The table also shows the spectral solar irradiance ($k_{b \text{ Land } 5}$) of each of the Landsat-5 TM bands at the top of the atmosphere.

Table 5 also highlights the calibration coefficients for the additive and multiplicative terms related to radiance and reflectance for Landsat-8 OLI/TIRS.

Table 4. Calibration coefficients for converting gray levels to spectral radiance and monochromatic reflectance of each of the multispectral bands of the TM sensor's Landsat-5 satellite images.

Band	Wavelength (μm)	TM sensor calibration coefficient ($\text{W m}^{-2} \text{sr}^{-1} \mu\text{m}^{-1}$)		Spectral solar irradiance ($k_{b \text{ Land } 5}$) at the top of the atmosphere ($\text{W m}^{-2} \mu\text{m}^{-1}$)
		L_{min}	L_{max}	
1 - Visible (blue)	0.452 – 0.518	-1.52	169	1983
2 - Visible (green)	0.528 – 0.600	-2.84	333	1796
3 - Visible (red)	0.626 – 0.693	-1.17	264	1536
4 - Near-Infrared	0.776 – 0.904	-1.51	221	1031
5 - Short-wave Infrared	1.567 – 1.784	-0.37	30,2	220
6 - Thermal Infrared	10.45 – 12.42	1.2378	15.3032	N/A
7 - Short-wave Infrared	2.097 – 2.349	-0.15	16.5	83.44

Source: Adapted from NASA / USGS (2019) and Chander et al. (2009).

Table 5. Calibration coefficients for converting gray levels to spectral radiance and monochromatic reflectance of each of the multispectral bands in the Landsat-8 satellite images from OLI/TIRS sensors.

Landsat-8 OLI / TIRS sensors	Spectral radiance					
Multispectral band	09/03/2013		09/22/2014		08/24/2015	
	Add_{rad}	Mult_{rad}	Add_{rad}	Mult_{rad}	Add_{rad}	Mult_{rad}
2 - Visible (blue)	-63.18751	0.012638	-63.80761	0.012762	-62.89022	0.012578
3 - Visible (green)	-58.22675	0.011645	-58.79816	0.011760	-57.95280	0.011591
4 - Visible (red)	-49.10008	0.009820	-49.58192	0.009916	-48.86907	0.009774
5 - Near Infrared (NIR)	-30.04680	0.0060094	-30.34166	0.0060683	-29.90543	0.0059811
6 - Short-wave Infrared (SWIR) 1	-7.47237	0.0014945	-7.54570	0.0015091	-7.43721	0.0014874
7 - Short-wave Infrared (SWIR) 2	-2.51859	0.0005037	-2.54330	0.0005087	-2.50674	0.0005014
10 - TIRS 1	0.10000	0.0003342	0.10000	0.0003342	0.10000	0.0003342
Landsat-8 OLI / TIRS sensors	Monochromatic reflectance					
Multispectral band	Add_{ref}		Mult_{ref}			
2 - Visible (blue)	-0.1		0.00002			
3 - Visible (green)	-0.1		0.00002			
4 - Visible (red)	-0.1		0.00002			
5 - Near Infrared (NIR)	-0.1		0.00002			
6 - Short-wave Infrared (SWIR) 1	-0.1		0.00002			
7 - Short-wave Infrared (SWIR) 2	-0.1		0.00002			
10 - TIRS 1	-0.1		0.00002			

Source: Adapted from NASA / USGS (2019).

The spectral radiance in each Landsat-5 band of the TM sensor was determined according to Equation 1 (Chander et al., 2009).

$$L_{b \text{ Land } 5} = L_{\min b} + \left(\frac{L_{\max b} - L_{\min b}}{254} \right) \times (DN_b - 1) \quad (1)$$

where, $L_{b \text{ Land } 5}$ ($W \text{ m}^{-2} \text{ sr}^{-1} \mu\text{m}^{-1}$) is the spectral radiance of each pixel in each band of Landsat-5; b (subscribed) represents each of the satellite bands; $L_{\min b}$ and $L_{\max b}$ ($W \text{ m}^{-2} \text{ sr}^{-1} \mu\text{m}^{-1}$) are the minimum and maximum spectral radiations, respectively (Table 4); DN is the pixel intensity (digital number between 0 and 255 gray levels).

The determination of the spectral radiance in the Landsat-8 satellite images of the OLI sensor was carried out from Equation 2 (Chander et al., 2009).

$$L_{b \text{ Land } 8} = \text{Add}_{\text{rad}} + \text{Mult}_{\text{rad}} \times DN_b \quad (2)$$

where, $L_{b \text{ Land } 8}$ ($W \text{ m}^{-2} \text{ sr}^{-1} \mu\text{m}^{-1}$) is the spectral radiance in each band of Landsat-8, based on the terms additive (Add_{rad}) and multiplicative (Mult_{rad}) related to the radiance (Table 5); DN is the pixel intensity (a digital number between 0 and 65,535 levels of gray, high level of detail of the image, ensuring more information about the study area).

From the radiance, the monochrome reflectance of the Landsat-5 satellite images determined the TM sensor, based on the spectral solar irradiance of each band at the top of the atmosphere ($k_{b \text{ Land } 5}$, Table 4), Equation 3 (Chander et al., 2009).

$$r_{b \text{ Land } 5} = \frac{\pi \times L_{b \text{ Land } 5}}{k_{b \text{ Land } 5} \times \cos \theta \times d_r} \quad (3)$$

where, $r_{b \text{ Land } 5}$ ($W \text{ m}^{-2} \text{ sr}^{-1} \mu\text{m}^{-1}$) is the monochromatic spectral reflectance in each band of the Landsat-5 TM; θ is the solar zenith angle, obtained through the

angle of elevation of the Sun, provided by NASA/USGS; d_r is the square of the ratio between the average and instantaneous distances between the Earth and the Sun on a given day of the year.

Monochromatic reflectance for Landsat-8 OLI was determined from Equation 4 (Chander et al., 2009).

$$r_{b \text{ Land } 8} = \frac{(\text{Add}_{\text{ref}} + \text{Mult}_{\text{ref}} \times \text{DN}_b)}{\cos \theta \times d_r} \quad (4)$$

where $r_{b \text{ Land } 8}$ ($\text{W m}^{-2} \text{ sr}^{-1} \mu\text{m}^{-1}$) is the monochrome reflectance in each band of Landsat-8 OLI, also based on the terms additive (Add_{ref}) and multiplicative (Mult_{ref}), related to reflectance (Table 5).

The square of the ratio between the average and instantaneous distances between the Earth and the Sun was determined from Equation 5 (Iqbal, 1983).

$$d_r = 1 + 0.033 \times \cos\left(\frac{\text{DSA} \times 2 \times \pi}{365}\right) \quad (5)$$

where DSA is the sequential day of the year; the cos function argument in radians.

To evaluate and characterize the conditions of changes in the Caatinga vegetation cover over time, the vegetation index adjusted to the soil (SAVI) was determined through the satellite reflective bands. It is an index that characterizes the condition of plant biomass, also used in the mapping of irrigated agriculture areas and in detecting the effects of droughts, especially in the regions of Northeast Brazil. The choice and application of this index alleviate limitations imposed by other vegetation indices on the degradation and desertification of areas, such as, for example, the normalized difference vegetation index (NDVI). SAVI seeks to mitigate antecedent soil effects through an adjustment factor, which is dependent on the type of soil in the study area (Ribeiro et al., 2016). The SAVI index was determined according to Equation 6 (Allen et al., 2002; Vorovencii, 2015).

$$\text{SAVI} = \frac{(1 + L) \times (r_{b \text{ IV}} - r_{b \text{ V}})}{(L + r_{b \text{ IV}} + r_{b \text{ V}})} \quad (6)$$

where $r_{b \text{ IV}}$ and $r_{b \text{ V}}$ are the respective reflective bands 4 and 3 of the Landsat-5 of the TM sensor and bands

5 and 4 of the Landsat-8 of the OLI sensor. They are bands of near and red infrared, respectively; L is the ground adjustment constant. In the present study, the value adjustment factor 0.5 (referring to an intermediate vegetation cover, such as the semiarid regions with Caatinga vegetation; Silva and Galvncio, 2012) was used, on a scale ranging from 0 (similar to NDVI) a 1 (low vegetation cover), indicated according to the density of the local vegetation cover (Huete, 1988; Allen et al., 2007a).

The landscape pattern, that is, the Spatial-temporal heterogeneity was evaluated and characterized by the MSDI, corresponding to the “Moving standard deviation index” calculated using a 3×3 filter applied to the reflective bands 3 (Landsat-5 TM) and 4 (Landsat-8 OLI) in the red range, Equation 7 (Xu et al., 2009; Vorovencii, 2015).

$$\text{MSDI} = \sqrt{\frac{\sum_{i=1}^N (\text{DN}_i - \overline{\text{DN}})^2}{N}} \quad (7)$$

where N is the number of pixels in the 3×3 filter ($N = 9$); DN_i is the digital number of the pixel “ i ” in each nine-pixel window; $\overline{\text{DN}}$ is the value of the average digital number for each nine-pixel window.

Through pre-established rules for the study area, a local methodology by decision tree was developed using the response patterns of indicators such as SAVI, albedo, and MSDI to classify the risk of environmental degradation in different degrees (low degradation; moderate; high and severe, Table 6) through the heterogeneity of soil uses in the region (Silva et al., 2019).

It consisted of creating ranges of values for each indicator according to the degree of risk of degradation in the study area. The ranges of the values were observed pixel by pixel in different conditions and carefully chosen according to the specificities and targets in each soil use, confirmed by the thematic classification of the maps of cover and soil use in the region (Figure 2).

In this context, the values were pre-established and tabulated to compose the rules of classification of the risk of degradation in different degrees according to their indicator indices (SAVI; MSDI and Albedo), for the semiarid region of study (Table 6).

Table 6. Pre-established rules per decision tree for the risk of environmental degradation in the semiarid region.

Environmental degradation risk classification	Indicator indices		
	SAVI	MSDI	Albedo (α_{sur})
Water / Non-existent	<0.00 ou >0.40	>0.00	>0.00
Low	0.31 – 0.40	0.00 – 4.0	0.14 – 0.30
Moderate	0.16 – 0.30	0.00 – 3.0	0.00 – 0.27
High	0.06 – 0.15	0.00 – 2.0	0.14 – 0.30
Severe	0.00 – 0.05	>0.00	>0.30

The surface albedo (α_{sur}) was determined based on studies developed in different semiarid regions, including Brazil (Allen et al., 2002; Bezerra et al., 2014; Silva et al., 2016; Silva et al., 2019). It is an important indicator that determines the energy balance and the change in micrometeorological conditions (temperature, aridity, humidity, etc) of the surface affected by degradation and/or desertification, Equation 8 (Xu et al., 2009; Vorovencii, 2015; Silva et al., 2016; Silva et al., 2019).

$$\alpha_{sur} = \frac{\alpha_{toa} - \alpha_{atm}}{\tau_{sw}^2} \quad (8)$$

where α_{toa} is the planetary albedo (without atmospheric correction), based on the weight coefficients, suggested for the TM sensor by Allen et al. (2002) and the OLI sensor by Silva et al. (2016); α_{atm} is the reflectance of the atmosphere (0.03) according to Bastiaanssen (2000), Allen et al. (2002) and Silva et al. (2016) and τ_{sw} is the atmospheric transmissivity at the time of the satellite's passage according to Allen et al. (2007b).

The surface temperature (T_s , K) was determined by the emissivity in the spectral domain of the thermal band (ϵ_{NB}), using the spectral radiance (L_b , $W m^{-2} sr^{-1} \mu m^{-1}$) of the thermal band (6) of the satellite Landsat-5 TM and the thermal band (10) of Landsat-8 TIRS, according to Equation 9 (Allen et al., 2002).

$$T_s = \frac{K_2}{\left(\frac{\epsilon_{NB} \times K_1}{L_b} + 1\right)} \quad (9)$$

where K_1 and K_2 are calibration constants for the TM sensor thermal bands, with values of $607.76 W m^{-2} sr^{-1} \mu m^{-1}$ and $1260.56 K$, respectively. For the TIRS sensor, the respective values were $774.89 W m^{-2} sr^{-1} \mu m^{-1}$ and $1321.08 K$, according to NASA/USGS. The temperature found was transformed from Kelvin (K) to degrees Celsius ($^{\circ}C$).

Statistical analysis

The quantitative results of thematic maps of the biophysical parameters albedo and surface temperature were subjected to descriptive statistics by measures of central tendency (mean, mode, median) and dispersion (minimum - Min, maximum - Max, standard deviation - SD and coefficient of variation - CV), to monitor environmental changes due to possible anthropic actions and local climate changes. Thematic maps of micrometeorological biophysical parameters were also evaluated for their Spatial-temporal variability using CV values (%), according to the classification criteria proposed by Warrick and Nielsen (1980), with low variability when $CV < 12\%$; medium variability with values of $12 < CV < 60\%$ and high variability when expressing $CV > 60\%$.

Thematic maps of classification of the risk of degradation in different degrees were subjected to an assessment of precision and statistical quality, by confusion matrix, regarding the measures of general precision and Kappa coefficient, performed for each image based on a random sampling of a set of dots (pixels) concerning the same locations in each image for each degree of risk of degradation (Landis and Koch, 1977; Xu et al., 2009; Vorovencii, 2015; Silva et al., 2019).

Results and discussion

Figure 2 illustrates the annual spatial thematic map of cover and soil use in the municipality of Iguatu-CE, referring to the Spatial-temporal analysis of the present study, highlighting the main soil uses in the years 2008 (Figure 2A), 2009 (Figure 2B), 2011 (Figure 2C), 2013 (Figure 2D), 2014 (Figure 2E) and 2015 (Figure 2F). The map was developed using spatial data and thematic classifications from the Brazilian Annual Land Use and Land Cover Mapping Project (MapBiomas Brazil) – Thematic classification of the Caatinga Biome, which works with Landsat satellite images.

Figure 2. Annual spatial thematic map of the thematic classification of cover and soil use, in the years 2008, 2009, 2011, 2013, 2014 and 2015, in the municipality of Iguatu, Ceará, Brazil.

Therefore, the quantification of micrometeorological biophysical parameters of the energy balance, highlighting the albedo and the surface temperature, as well as the development of thematic maps of the environmental degradation risk of the Earth's surface promoted important responses through the statistical analysis of the results in the different soil uses, favoring an outstanding assessment in the environmental monitoring of the

patterns and conditions of changes in the natural vegetation of the Caatinga over time in the semiarid region of the present study.

Figure 3 illustrates the thematic map of the Spatial-temporal distribution of the surface albedo (α_{sur}) of the semiarid region, which varied between the values of 0.01 and 0.45. The albedo behavior showed medium variability, confirmed by CV values (21.0 to 28.0%, Table 7).

Figure 3. Spatial-temporal distribution of the surface albedo in the semiarid region in the days of passage of satellites: 09/21/2008 (A); 06/20/2009 (B); 08/29/2011 (C); 09/03/2013 (D); 09/22/2014 (E) and 08/24/2015 (F).

The lowest values of α_{sur} were found on water bodies, highlighted, in the reservoirs to the northwest (Trussu) and northeast (Orós) of the region (blue pixels), varying between 0.01 and 0.08 (Figure 3). Rodrigues et al. (2009) analyzed the albedo in the same semiarid region, more specifically in the Trussu reservoir, and observed values for the dry period below 0.04. The authors pointed out that the values in this range of behavior are generally indicative of clean waters, with little suspended sediment load. However, in the rainy season, they observed an upward trend, varying between 0.05 and 0.11, a behavior associated with the accumulation of impurities carried by rainwater and the absence of clean water, corroborating, in general, with the present study. Likewise, Giongo and Vettorazzi (2014) stressed the same particularities, finding values of albedo on even higher water surfaces, between 0.05 and 0.18.

Regarding the highest values of α_{sur} , were observed in urban areas and exposed soil, varying between 0.21 and 0.30 and between 0.31 and 0.45,

respectively. In Caatinga vegetation, the value of α_{sur} was between 0.13 and 0.16, in agricultural areas it was between 0.15 and 0.22 (Figure 3). MapBiomass Brazil (2019) highlighted the annual results of the different soil uses in the region between the study period of 2008 and 2015. Such ones showed, over time, a reduction of the forest areas in the Caatinga, by 1,165 hectares (ha). While agricultural activities grew in the same period in 5,888 ha, also highlighting the growth in urban infrastructure areas, in 18 ha.

In this sense, with the growth of sectors such as agriculture, livestock and urban areas that refers to the increase in the local population, the pressures on water resources in the semiarid region further increase, as is also highlighted by MapBiomass Brazil (2019), through the quantification of water bodies, which decreased by 4,708 ha, between 2008 and 2015.

It is interesting to highlight a similar behavior of thematic maps over time, presented both in the central part of the maps, as well as in some areas to the south, southwest, north, and northeast

areas high values of albedo (red pixels), that is, both in the rainy years as in the dry years, explained due to the presence and increase of the urban area (central area of the maps) and, mainly, due to the little and/or absent vegetation cover of Caatinga (south, southwest, north and northeast areas), that in this case it can be characterized as areas in process of environmental degradation or even the existence of already degraded areas, motivated by deforestation and burning (Figure 3).

Silva et al. (2016) also found similar albedo values, between 0.28 and 0.31, justifying such result to the existence of the urban area (city), in the areas of water bodies were values between 0.03 and 0.08 and on the agricultural areas between 0.16 and 0.18, similar to the present study, in this case, the variation is mainly due to the different types of crops, however, in some areas of the region, albedo values

above 0.31 were confirmed, confirming which are areas that were devoid of cultivation, as was also observed by Giongo and Vettorazzi (2014).

From the statistical values (Table 7), the increase in the mean values of α_{sur} stands out, which varied between 0.14 and 0.20. This result is linked to several factors to which the dry period contributes negatively. It is worth noting that this increase is due to the presence of exposed soil, which is generally more prevalent in images of the dry season, which also grow, in part, due to greater spectral confusion between soil and vegetation. On the other hand, however, the study region is in the Brazilian semiarid (region of marked water deficit) with predominant vegetation of the Caatinga biome, which has leaf fall in the dry period as a striking defense physiological characteristic (Rodrigues et al., 2009; Bezerra et al., 2014).

Table 7. Statistical parameters and quantitative and spatial variability of the thematic map of the surface albedo of the semiarid region, municipality of Iguatu-CE.

Satellite	Date of passage	Surface albedo (α_{sur})						
		Min	Max	Average	Median	Mode	SD	CV (%)
Landsat-5 TM sensor	09/21/2008	0.03	0.37	0.16	0.14	0.14	0.04	25.0
	06/20/2009	0.01	0.39	0.14	0.14	0.14	0.03	21.0
	08/29/2011	0.03	0.38	0.14	0.13	0.13	0.04	28.0
Landsat-8	09/03/2013	0.02	0.41	0.20	0.19	0.19	0.05	25.0
OLI / TIRS	09/22/2014	0.05	0.44	0.20	0.19	0.19	0.05	25.0
sensors	08/24/2015	0.03	0.45	0.20	0.19	0.19	0.05	25.0

Arraes et al. (2012) also observed an upward trend in the average values of albedo, mainly for anthropic areas, in general, they were between 0.11 and 0.19, corroborating the results of Oliveira et al. (2015), who in turn, found mean albedo values ranging between 0.13 and 0.21, both well directed by the present study.

Gutiérrez et al. (2014) in a case study on drought in Brazil, highlighted its strong intensity in the years 2012 and 2013 (years of high water deficit), especially in the semiarid regions of the state of Ceará, which affected the main reservoirs, pointing out significant losses in rainfed agriculture between 80 and 90% in the cultivation of corn and beans, evidencing several conflicts mainly to rural workers. It is also noteworthy that, between the years with below-average rainfall (2013 to 2015), according to the INMET rainfall records for the region (Table 2), 2014 was rainier than the years 2013 and 2015, thus, observing a decrease in the albedo values on the years previously mentioned (Figure 3). 2015 was El Niño's year, and an increase in albedo values was

also observed during this period (Marengo et al., 2018).

In addition to drought, even more aggravating factors such as intensive human practices and activities on soil use and occupation through inadequate management of irrigated agriculture, deforestation, burning and civil construction influence energy exchanges between the surface and the atmosphere, favoring the increase in areas of exposed soil and impermeable areas that act directly in raising the values of α_{sur} , being extremely important to emphasize that areas without vegetation affect the hydrological conditions and soil properties, resulting in the general loss of ecosystem services, becoming serious threats to sustainable livelihoods, as a result, they can promote environmental degradation and soil desertification over time (D'Odorico et al., 2013).

Brandt et al. (2014) in a research on environmental changes by remote sensing in semiarid regions located in Senegal and Mali, also noted that climate change and anthropic activities caused changes in the natural environment,

highlighting mainly drought events (low rainfall and high temperatures) and the increase in cultivation areas, especially in the dry season, causing the environment to degrade over time.

Also, because of the rains that preceded the period of view of the satellites, some environmental changes were found, which caused the decrease of α_{sur} through the increase of soil moisture, favoring the recovery and conservation of the plant mass, especially on the 06/20/2009 (Figure 3B), this is due to the high rainfall rates of the previous quarter (March, April, and May), which together are 624.6 mm (Table 2) and also the rainfall before the images observed in the 20 days, of 14.2 mm (Table 1).

Thus, it is worth mentioning that the Caatinga is known for its high resilience power,

which is confirmed by the immediate formation of plant biomass (increase in the leaf canopy) in response to rain events. In this sense, the previous rainy events caused an accelerated return before the components of the energy balance and radiation balance, affecting the values of α_{sur} with the reduction of radiation reflected by the soil (Rodrigues et al., 2009; Arraes et al., 2012; Oliveira et al., 2012).

Figure 4 illustrates thematic maps of the Spatial-temporal distribution of the surface temperature (T_s) of the semiarid region, with values between 18.82 and 47.00 °C, with a low variability behavior, confirmed by the CV values (5.0 to 10.0%, Table 8).

Figure 4. Spatial-temporal distribution of surface temperature in the semiarid region in the days of passage of satellites: 09/21/2008 (A); 06/20/2009 (B); 08/29/2011 (C); 09/03/2013 (D); 09/22/2014 (E) and 08/24/2015 (F).

The reservoirs Trussu (northwest region of the maps) and Orós (the northeastern region on the maps) showed lower temperatures for all thematic maps, varying between the values of 18.82 and 21.62 °C (Figure 4). In general, based on the statistical data in Table 7, the day 06/20/2009 (Figure 4B) presented

the lowest values of T_s , due to the rains of the previous quarter (624.6 mm, Table 4) and especially due to rainfall antecedents to the passage of the satellites, of 14.2 mm (Table 1), which favored the contribution of humidity and, consequently, the increase in vegetal cover, directly providing these

responses in the region. Bezerra et al. (2014) observed that, in addition to the rain regime, the spatialization of temperature takes place analogous to the distribution of local vegetation cover, also relating to the seasonality of meteorological variables such as air temperature and incident global solar radiation.

In this sense, the surface of the thematic maps stands out on 09/21/2008 (Figure 4A), 06/20/2009 (Figure 4B) and 08/29/2011 (Figure 4C), which presented lower average temperatures (Table 8). These maps showed water mirrors noticeably higher due to the high volumes of rain observed in the rainy season of these years (Table 2), and they were years with rainfall above the historical average

of the region (1392.8 mm - year 2008; 1079.2 mm - year 2009; 1335.6 mm - year 2011, Table 2). In this way, the rainfall rates are quite significant for the region, as they have benefited the appearance of areas with cold spots, generating a microclimate favorable to local environmental conditions. Souza et al. (2016) also encountered lower temperature values in water bodies and higher in urban areas and areas of exposed soil with the respective temperatures of 31.4 and 31.1 °C. Tejas et al. (2017), similarly, analyzed a result similar to this research, where the maps of the orbital images provided areas with cold spots, possibly formed by the close presence of bodies of water.

Table 8. Statistical parameters and quantitative and spatial variability of the thematic map of the surface temperature of the semiarid region, municipality of Iguatu-CE.

Satellite	Date of passage	Surface temperature – T _s (°C)						
		Min	Max	Average	Median	Mode	SD	CV (%)
Landsat-5 TM sensor	09/21/2008	18.82	39.64	31.87	32.30	33.09	3.33	10.0
	06/20/2009	16.54	29.01	22.90	22.52	21.49	1.25	5.0
	08/29/2011	19.28	39.24	30.31	30.55	30.55	2.89	9.0
Landsat-8	09/03/2013	22.79	43.36	36.13	36.29	36.61	3.18	9.0
OLI / TIRS sensors	09/22/2014	23.74	47.00	35.75	35.86	34.71	2.97	8.0
	08/24/2015	21.86	45.05	36.45	36.36	36.72	2.75	7.0

The high temperatures were observed on 09/03/2013, 09/22/2014 and 08/24/2015 (Table 8), precisely the years with lower rainfall regimes (Table 2) that possibly contributed to the appearance of heat, mainly over the urban area (23.20 to 24.07 °C), exposed soil (25.20 to 47.00 °C) and in areas with little vegetation (24.08 to 25.01 °C). It is worth mentioning that this is also due to the period of image selection, corresponding to the dry season in the region.

In the Caatinga vegetation area, on the average, the values were between 22.42 and 25.10 °C and in irrigated agriculture areas between 21.63 and 22.41 °C (Figure 4). It is noteworthy that the days 09/22/2014 (Figure 4E) and 08/24/2015 (Figure 4F), in urban areas, values were observed significantly higher than 30 °C, reaching some points at 36 °C, possibly related to the territorial growth of urban infrastructure, which expanded by 18 ha, as highlighted by MapBiomas Brazil (2019), between 2008 and 2015. Oliveira et al. (2012) also observed in the urban centers of the cities of Pombos and Vitória de Santo Antão, Pernambuco, a sudden change in temperature values, which were above 30 °C.

The deficits in rainfall (Table 2) and periods of drought observed over time in the study region together with the gradual increase in surface temperature have increased the risk of environmental degradation. This is because in the study area the cover and soil use maps (Figure 2) and also in the maps of the risk of degradation (Figure 5) showed an increase in the areas of exposed soil and the replacement of forest areas by the vegetation of pasture (MAPBIOMAS BRAZIL, 2019).

The drought extended mainly from 2012 to 2015 in the various semiarid regions, especially in the study area (Iguatu-CE), which directly affected subsistence agriculture, having an impact on local socio-economic conditions.

The temperature maps had similar patterns and analogous to the maps of the surface albedo, both in the central (urban) area and in the areas to the south and southwest, and also in the areas to the north and northeast, in perception of high values of T_s (pixels red) in the semiarid region (Figure 4).

In this sense, the characterization of areas in the possible process of environmental degradation and/or degraded is reinforced. Since the year 2012, drought events have afflicted the Brazilian semiarid region with the dry season presenting accentuated

and long periods, due to this, the water bodies presented smaller and smaller water mirrors over time, favoring the increase of the areas of exposed soil, as presented in the Trussu and Orós reservoirs, on 09/03/2013 (Figure 4D), 09/22/2014 (Figure 4E) and 08/24/2015 (Figure 4F). This causes the soil in these areas to reach higher average temperatures because it receives a greater load of solar radiation, consequently increasing the areas with heat stains by at least 6 °C between the days of the selected images (Table 8).

Lins et al. (2017) pointed out that in studies aimed at the evaluation of biophysical parameters, in question at surface temperature, higher values are usually expected on exposed soil areas or urban areas, where they observed an increase in temperature, on average, of 3,34 °C when passing from regions with abundant vegetation to areas of exposed soil, and values in the urban area (33.94 and 35.75 °C) that corroborate with the present research.

Among the factors that most interfered in the response patterns of the biophysical parameter's albedo and surface temperature in a Caatinga

environment in the dry season, was the presence of isolated rains and the resilience of the vegetation type, which in turn, caused an increase and/or decreased energy balance component. Mariano et al. (2018) pointed out that albedo is significant in the surface energy balance, being one of the main stimulators of evapotranspiration in the partition of sensitive and latent heat flows.

In other research by D'Odorico et al. (2013), Gutiérrez et al. (2014) and Mariano et al. (2018) warned that the worsening of soil degradation in semiarid regions is one of the most catastrophic results of long-term drought events and anthropic activities. However, through the assessment of climate impacts, induced mainly by the action of man in the environment, essential information can be obtained for decision-makers to mitigate degradation in the regions of the Brazilian semiarid.

Figure 5 shows the Spatial-temporal classification of thematic maps of the risk of low, moderate, high and severe degradation in the different soil uses in the semiarid region of Iguatu-CE between the period 2008 and 2015.

Figure 5. Spatial-temporal monitoring of the risk of environmental degradation in different degrees in the semiarid region in the days of passage of the satellites: 09/21/2008 (A); 06/20/2009 (B); 08/29/2011 (C); 09/03/2013 (D); 09/22/2014 (E) and 08/24/2015 (F).

Detections of changes in the earth's surface in the semiarid region of the study are more precisely associated with long periods of drought, thus being reinforced by the absence and/or presence of rainy events. As a result, it is worth highlighting the characteristics of defense or resilience of the natural environment of the Caatinga vegetation.

However, in the Spatial-temporal analysis, some areas maintained similar behavior under conditions of negative changes such as areas affected by environmental degradation, possibly motivated by anthropic activities such as, for example, some areas in the southern region and in the central areas highlighted on maps, which most effectively presented a risk of severe environmental degradation (Figure 5). This behavior of the risk of degradation corroborates with the thematic map of cover and soil used in the region (Figure 2) when it highlights the reduction of forest areas and the increase of agriculture and livestock and urban area in the study area. In conclusion, Pinheiro et al. (2018) in a study on the efficiency of natural Caatinga vegetation in an experimental sub-basin in the Upper Jaguaribe hydrographic basin (Iguatu-CE), warned that practices that lead to deforestation in the Caatinga replacing pasture vegetation favor environmental degradation.

Severe degradation can quickly favor more the path to the desertification of important areas in

the Iguatu-CE region, mainly threatening the region's subsistence agriculture, with the fragmentation of agricultural areas.

Thematic maps of the risk of degradation also showed worrying conditions over reservoirs, rivers, and lagoons over time (Figure 5), showing that drought events directly affected hydric availability, directly damaging human supply, animal drinking and the agricultural production system in the semiarid region.

Figure 6 shows the quantification of the areas most affected by the severe effects of drought and also by anthropic activities in the semiarid region of Iguatu-CE. The areas at risk of moderate and low degradation on 06/20/2009 were visibly improved through the resilience of the Caatinga vegetation, with the respective percentages of 34.70% (356.86 km²) and 23.55% (242.24 km²), favoring mainly the regression of the percentages of the risks of severe degradation, in 8.50% (87.41 km²) and high in 24.70% (254.01 km²) of the total area. This behavior is directly related to the regularity of previous rainfall regimes (Table 2). This type of response and maintenance of the Caatinga vegetation cover is quite remarkable in the semiarid regions of Brazil. These results corroborate those of Silva et al. (2019) when they observed that the risk of severe degradation regressed due to the rains preceding the passage of the satellite.

Figure 6. Quantification of areas with different risks of environmental degradation in the semiarid region in the days of passage of the satellites: 09/21/2008; 06/20/2009; 08/29/2011; 09/03/2013; 09/22/2014 and 08/24/2015.

The risks of high and severe degradation are highly striking in the spatial-temporal analysis, which stood out even more in the images of the days 09/03/2013, 09/22/2014 and 08/24/2015 (Figure 6), times of high water deficit (low soil moisture), alert

condition and worrying factor, which favors the increase in surface temperature, among other factors, potentiating the desertification of areas in the region. Vorovencii (2015) points out that the decrease in vegetation cover over dry surfaces directly affects the

surface temperature, as well as the humidity of the air, thus being able to influence the circulation of air mass and the local rain regimes.

Vieira et al. (2015) in a survey on the identification of areas susceptible to desertification in Northeastern Brazil, highlighted during 11 years (2000-2010), an increase of 3% in the area with high susceptibility due to the inappropriate use and management of the land. The authors stated that the main factors that contribute to the worsening of land degradation and desertification are agriculture, livestock, deforestation, and burning.

The day 08/24/2015 was the most affected in all environmental aspects, with the areas at risk of high, severe and moderate degradation being the most expressive among the Spatial-temporal analysis, with percentages of 51.96% (534.38 km²), 23.79% (244.69 km²) and 17.56% (180.64 km²) of the total area of the region, respectively. However,

still, it presented itself as the time of less recovery of Caatinga vegetation, due to the risk of low degradation, with a percentage of only 4.44% (45.69 km²) of the total area (Figure 6).

Vieira et al. (2013) analyzed the mapping of land use and land cover in northeastern Brazil, they also stressed the replacement of natural Caatinga vegetation by areas of pasture and agriculture. According to a study by MMA / IBAMA (2010), for the period from 2002 to 2008, 40% of the Caatinga area was replaced by different soil uses, presenting a constant change in its landscape at a rate of 0.3% per year.

Figure 7 illustrates the quantification of areas covered by water bodies in the region, showing that hydric availability has decreased considerably over time, mainly due to the severe drought effect in this study period.

Figure 7. Quantification of the areas covered by water bodies in the semiarid region in the days of passage of the satellites: 09/21/2008; 06/20/2009; 08/29/2011; 09/03/2013; 09/22/2014 and 08/24/2015.

The days 09/21/2008, 06/20/2009 and 29/08/2011 presented larger areas of water mirrors and hydric contribution, with percentages of 7.76% (79.84 km²), 8.55% (87.91 km²) and 7.40% (76.15 km²) of the total area of the region, respectively. However, as of 2012, drought became predominant in the Brazilian semiarid region (Gutiérrez et al., 2014; Marengo et al., 2016; Marengo et al., 2018). With that, the days 9/3/2013, 9/22/2014 and 8/24/2015 highlighted areas with much smaller water mirrors, representing percentages of only 4.35% (44.70 km²), 3.36 % (34.59 km²) and 2.24% (23.02

km²) of the total area, respectively (Figure 7). It is worth mentioning that the annual thematic map of the cover and soil use of the present study (Figure 2), based on thematic classifications of MapBiomas Brazil, corroborates and efficiently confirms the reduction of water bodies in the semiarid region.

Table 9 shows the statistical evaluation of the precision indexes and thematic quality of the maps of the risk of environmental degradation in the semiarid region. Highlighting that rules pre-established by decision tree for the study area were efficient.

Table 9. Statistical evaluation of the general precision and quality of the thematic maps of the risk of environmental degradation in the semiarid region.

Image date	Evaluation indexes of accuracy and thematic quality	
	Overall accuracy (%)	Kappa coefficient
09/21/2008	99.98	0.99
06/20/2009	98.75	0.96
08/29/2011	100.0	1.00
09/03/2013	99.78	0.99
09/22/2014	97.85	0.97
08/24/2015	95.66	0.94

The general precision varied between 95.66 and 100.00% and the Kappa coefficient between 0.94 and 1.00 (Table 9), highlighting the excellent accuracy and thematic quality of the maps of the risk of environmental degradation, according to the classification criteria of Landis and Koch (1977), which corroborated the statistical pattern of the study by Silva et al. (2019), through research also carried out in the region of the Brazilian semiarid, with precision index values ranging between 92.99 and 99.96% and Kappa between 0.88 and 0.99. In an analysis similar to the present study, Xu et al. (2009) also found in the thematic map's statistical standards of excellence, with precision ranging between 90.00 and 92.60% and Kappa between 0.87 and 0.90. Also noteworthy is the research by Vorovencii (2015), on the accuracy of thematic maps of the risk of desertification, which obtained excellent accuracy, ranging between 85.21 and 90.42%.

Studies in other images and also analyzing biophysical parameters such as vegetation indexes and soil moisture, in space and time, must be carried out to confirm that in addition to severe droughts, the extensive agriculture and livestock practice may be contributing to the growth of degraded areas, accelerating the desertification process in the region, as well as throughout the Brazilian semiarid.

Conclusions

The response patterns of the thematic maps of the risk of environmental degradation corresponded in a similar way to the response patterns of albedo and surface temperature.

The rules established by the decision tree and the use of indicator indices were effective for quantifying and monitoring the spatial-temporal risk of environmental degradation in different degrees, with a statistical assessment of precision and excellent thematic quality, detecting changes in the soil surface of the region semiarid, which in turn, is even more vulnerable to the effects of drought and anthropic activities.

The risks of high and severe degradation have been heightened over time, noting that the lack

of adequate management practices in agriculture, other anthropic activities, the absence of control measures and combating drought make it possible to increase areas in degradation processes, which substantially raised albedo and surface temperature in the semiarid region, consequently favoring soil desertification, mainly affecting agriculture with the fragmentation of agricultural areas.

Remote sensing is a strong ally for environmental studies in semiarid regions that do not have enough data available, making it impossible to understand the various changes and vulnerability patterns in the natural environment of Caatinga, especially in times of drought, thus becoming a high applicability tool in the mapping of heterogeneous areas on a large scale, contributing to the management and prior planning in decision making on hydric and natural resources, minimizing environmental degradation and susceptibility to the desertification of the semiarid regions of Brazil.

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