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Desertification climatic susceptibility to the Center-North region of Brazilian Semi-Arid

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Abstract

Desertification process is a phenomenon of high environmental and social complexity because it embraces a significant number of indicators and variables that inter relate and that complement the comprehension of this process. One of the most useful and applied ways of the study of desertification verification is through the calculation of the Aridity Index (AI). This way, this present study uses that methodology to verify the situation of AI in Center-North region of Brazilian Semi-Arid. The aim was to investigate the variety of AI and its classifications during the period between 1961 and 2015, using temporal series of 30 years, expressed in the time interval of 2005, 2010 and 2015. It was possible to observe that therefore some changes in AI in many locations, where quantitative changes happened in the area, increasing mainly to the conditions of aridity aggravation, there was not the meaningful occurrence of alteration in the Desertification Tendency classification.

Key words: Aridity Index, interpolation, IDP, spatialization

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1. Introduction

Brazilian Semi-Arid (SAB) comprises an area of approximately 981.000 km², containing 1.135 cities and approximately 23 million of inhabitants (INSA, 2012), being the semi-arid region the most populous in the world (Ab'Sáber, 1999). It is characterized in a general way by the instability between the offer and the demand of natural resources, because of the necessities of the population that live there.

In a specific way, they present a landscape variation more or less accentuated, because they are submitted to the particular weather conditions, soil, vegetation, social relation and, as a consequence, different ways of life (BRASIL, 2004).

This environment faces what United Nations Convention of Desertification Combat (UNCCD) classified, in 1997, as desertification. Understood as degradation of lands in arid, semi-arid, sub humid and dry regions, resulting from many factors, among them the climatic variation and the human activities. Land degradation comprises the degradation of soil, hydric resources, and vegetation.

The criteria used to delimitate these areas was the Aridity Index (AI) elaborated by Thornthwaite (1941, 1948) adjusted later by Penman (1953). This index has a relevant use in desertification study, its calculation in annual scale can indicate in regional scale that environmental conditions are submitted.

According to Maliva and Missimer (2012), AI helps in tendencies mapping whether temporal whether spatial, to the weather management of these areas that, because of the climatic severity, present bigger susceptibility to desertification occurrence and harm the environment and the population quality of life.

Working with the spatialization of AI, obtained by historic data of precipitation and temperature coming from climatic stations of Meteorology National Institute (INMET), it makes possible the spatial tracking and temporal analysis of this environment in a climatic risk situation. It was aimed in this work to investigate the variation of AI and its spatial and temporal distribution during 1961 and 2015, using the temporal series of 30 years, expressed in three different intervals (S2005, S2010 and S2015) to the region of SAB center-north.

2. Materials and methods

The study area defined by the distribution of 25 meteorology stations of Meteorology National Institute (INMET). It was selected a regional clipping aiming to highlight the center-north portion of Brazilian semi-arid, equivalent to an area of approximately 650.000 km², representing more than the half of Brazilian Semi-arid (Figure 1).

Figure 1 – Localization of stations and selected area for study.

It used historical data of annual total precipitation and average temperature compensated of 25 meteorological stations located in the states of Alagoas, Bahia, Ceará, Paraíba, Pernambuco, Piauí, and Sergipe. In table 1, it presented the historical period of data used to each meteorological station and its geographical coordinates.

Table 1 – geographic localization and period of data to each station collected at INMET.

Station	Longitude (º)	Latitude (º)	Períod	
			Beginning	End
Pão de Açúcar - AL	-37,43	-9,75	1977	2015
Monte Santo - BA	-39,29	-10,43	1961	2015
Senhor do Bonfim - BA	-40,18	-10,46	1977	2015
Remanso - BA	-42,10	-9,63	1961	2015
Paulo Afonso - BA	-38,21	-9,36	1962	2015
Jacobina - BA	-40,46	-11,18	1961	2015
Morro do Chapéu - BA	-41,21	-11,21	1962	2015
Irecê – BA	-41,86	-11,30	1973	2015
Serrinha - BA	-38,96	-11,63	1961	2015
Barra – BA	-43,16	-11,08	1977	2015
Cipó – BA	-38,51	-11,08	1961	2015
Cabrobó - PE	-39,33	-8,51	1963	2015
Petrolina - PE	-40,48	-9,38	1963	2015
Triunfo – PE	-38,11	-7,81	1961	2015
Monteiro - PB	-37,06	-7,88	1963	2015
Patos - PB	-37,26	-7,01	1976	2015
São Gonçalo - PB	-38,21	-6,75	1961	2015
Iguatu - CE	-39,29	-6,36	1961	2015
Tauá - CE	-40,41	-6,00	1964	2015
Campos Sales - CE	-40,38	-7,00	1963	2015
Barbalha - CE	-39,29	-7,31	1973	2015
Picos - PI	-41,48	-7,03	1966	2015
Bom Jesus do Piauí - PI	-44,11	-9,10	1971	2015
Floriano - PI	-43,01	-6,76	1971	2015
Itabaianinha - SE	-37,81	-11,11	1963	2015

Selection methodology of data was presented by Santos et al. (2016) in what consists in the selection of representative values of precipitation and temperature, what means, it used data of days in which there were rains, consecutive events or not, generating monthly total values over the years. Failures rejected and the days without rains were not selected. To the temperature values, it was used the data equal or superior to twenty (20) days of readings, consecutive or not, generating average values to the months. Failures and values lower than twenty (20) days of reading rejected.

With selected and calculated data, it was calculated the Aridity Index (AI). It was made using the Equation 1:

$$AI = Pr / ETP \qquad \text{Eq. 1}$$

where: Pr, annual precipitation (mm); ETP, annual potential evapotranspiration (mm).

The calculation of ETP followed the methodology proposed by Thornthwaite and Matter (1955), using Equation 2:

$$ETP = f \times 1,6\ (10 \times t / I)^a \qquad \text{Eq. 2}$$

where: ETP, potential evapotranspiration: f, a factor of adjustment attached to the latitude and month of the year; t, monthly average temperature and I, annual heat index. The index value is determined according to I, using the Equation 3:

$$a = 6,750 \times 10^{-3}\ I – 7,711 \times 10^{-5}\ I + 1,792 \times 10^{-2}\ I + 0,492 \qquad \text{Eq. 3}$$

Calculations of ETP were made using the “BHnorm61” program in electronic chart elaborated by Rolim et al. (1998) using besides the total of precipitation and the monthly temperature average, the latitude of each one of the studied stations and the capacity of available water (CAD). To the selected study it was used the value of CAD equals to 100 mm that, according to Sentelhas et al. (1999), when the calculation is made to climatologic reasons, that means, to the characterization of regional hydric availability, it is common to adopt the values varying between 75 to 125 mm.

With calculated AI it can be determined the climatic category to each region represented by the climatologic station, according to the methodology of United Nations Program on the Environment (UNEP, 1992) and from that, classify the level of desertification susceptibility, adapted from the classification proposed by Matallo Júnior and Schenkel (2003) (Table 2).

Table 2 – Climatic classification and susceptibility desertification level using the Aridity Index (AI)

Climatic categories	Aridity Index	Desertification susceptibility level
Humid	AI ≥ 1,00	Inferior to moderated
Sub humid humid	0,65<AI<1,00	Inferior to moderated
Sub humid dry	0,50 < AI ≤ 0,65	Moderated
Semi-arid	0,20< AI ≤0,50	High
Arid	0,05< AI ≤ 0,20	Very high
Hyper arid	AI≤0,05	Superior to very high

To this work, it was used a temporal clipping of three years to the specialization of AI. It was chosen the years of 2005, 2010, and 2015 aiming temporal analyses of the phenomenon in the study area. Values were collected closer to possible 30 consecutive years of data, according to the recommendation of *World Meteorological Organization* (WMO, 1989). This period is characterized because it is sufficiently long to filter inter annual variation or anomalies, but it is also short and sufficient to be able to show climatic tendencies.

To determine the temporal clipping, it was used movable averages, looking for the maximum of years to improve the AI representativeness following Lopes and Leal (2015) methodology. Aiming the comprehension of the adopted format, for example, the amplification of movable averages for Petrolina-PE station. The series of data has its beginning in 1963 and its ending in 2015, what allowed to build a series of 30 years from 2005, so there are the series S2005 that correspond to the average value of 30 years from 1975 to 2005; S2010, average values of 30 years of data from 1980 to 2010 and S2015, with the average of 1985 to 2015.

As final stage, it was made the spatialization of AI data using the interpolation of these different years (2005, 2010 and 2015) using the module of spatial analyze of software from Geographic Information System (SIG), ArcGIS 10.2, license used by the Geo Processing Laboratory and Remote Sensing of Semi-Arid Embrapa. It was used the statistic model Considerate Distance Inverse (IDP) with the potency of 3; such value was used concerning the work of Lopes at al. (2016) that point a good tendency to the data of stations used in this work. To delimit the area of influence of used stations was applied to the buffer operation in data of the location of stations that means, it was generated areas from a ray of 50 km in each meteorological station. Such method was necessary to not over estimation or under estimation of values interpolated to the chosen clipping.

3. Results and discussion

With INMET meteorological stations, it was possible to make a spatial analyze serving the study area, the use of more stations would be ideal, however, with the difficult access to historical data, these stations are determinant to the AI studies in Brazil. The adopted methodology in the selection of data in which failures was not considered to the precipitation and use of monthly average values that allowed to obtain data that represented the phenomenon that occurred in each station.

Temporal series of 30 years to each studied period (S2005, S2010 and S2015) obtained a series of data that, interpolated through the method of IDP interpolation using the value of potency 3, represented satisfactorily the evolution of AI phenomenon to every year.

In Figures 2, 3 and four are presented the results of interpolation of data of AI to the three periods (2005, 2010 and 2015) as the respective histograms and static values. Data were classified and attributed to 3 categories according to the Table 2.

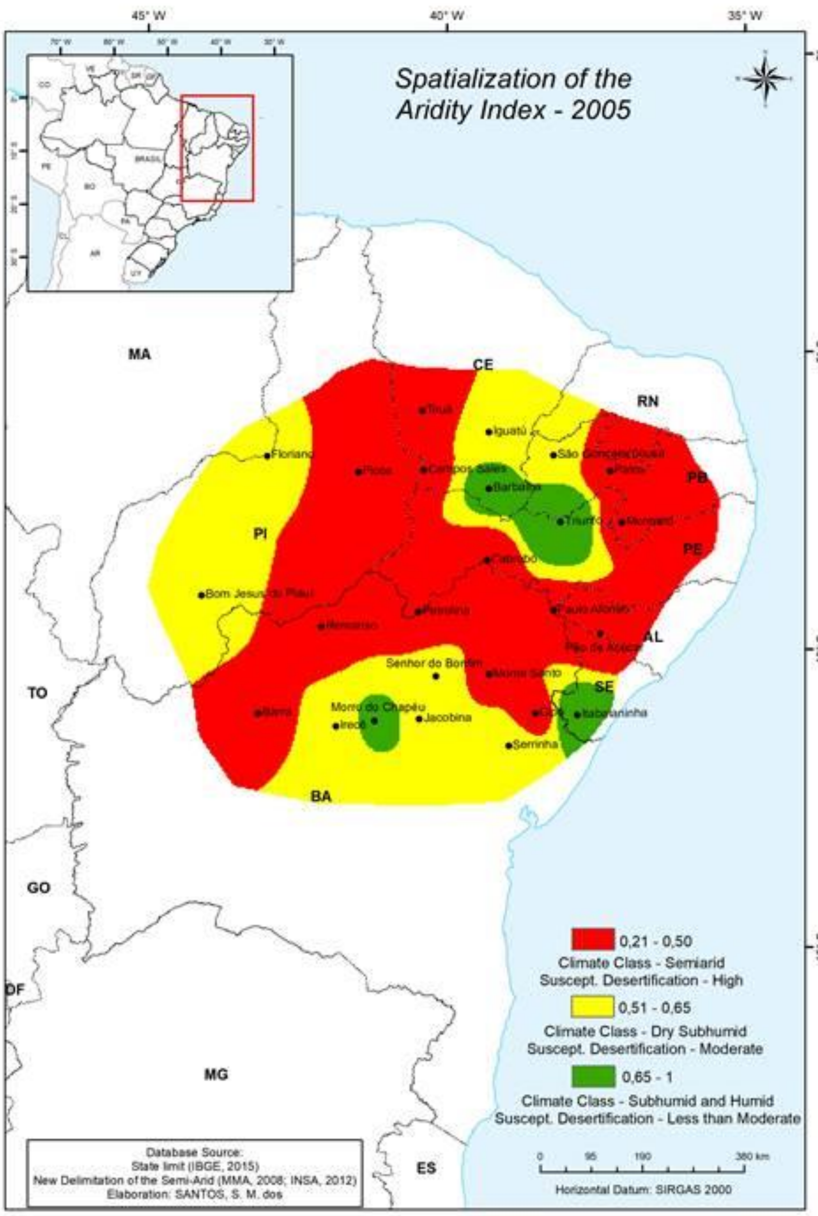

Figure 2 – Spatialization of series S2005 (data from 1975 to 2005), with the classification of desertification susceptibility to the year of 2005 with its respective histograms and statistical data.

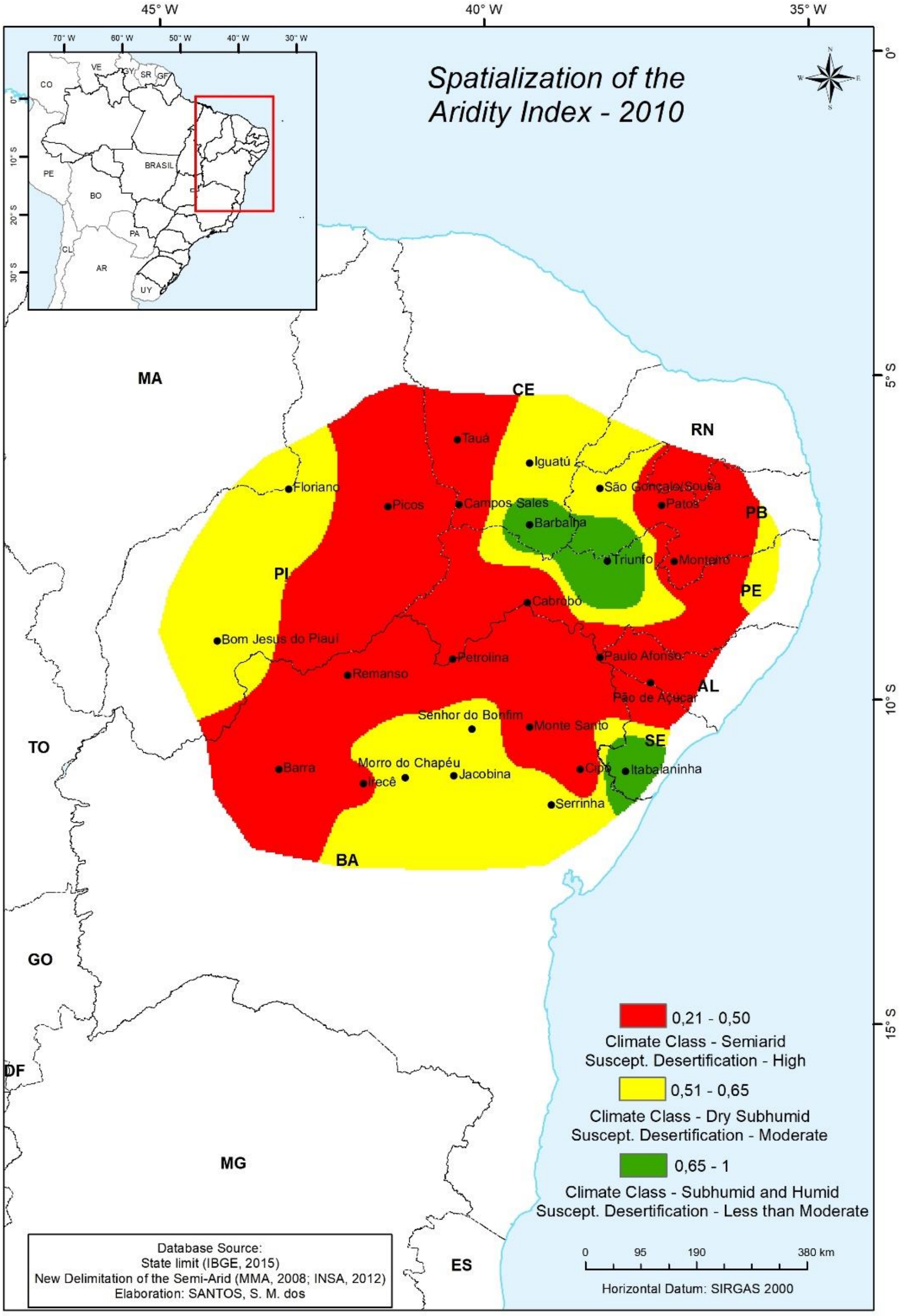

Figure 3 – Spatialization of series S2010 (data from 1980 to 2010), with the classification of desertification susceptibility to the year of 2010 with their respective histograms to the statistical data.

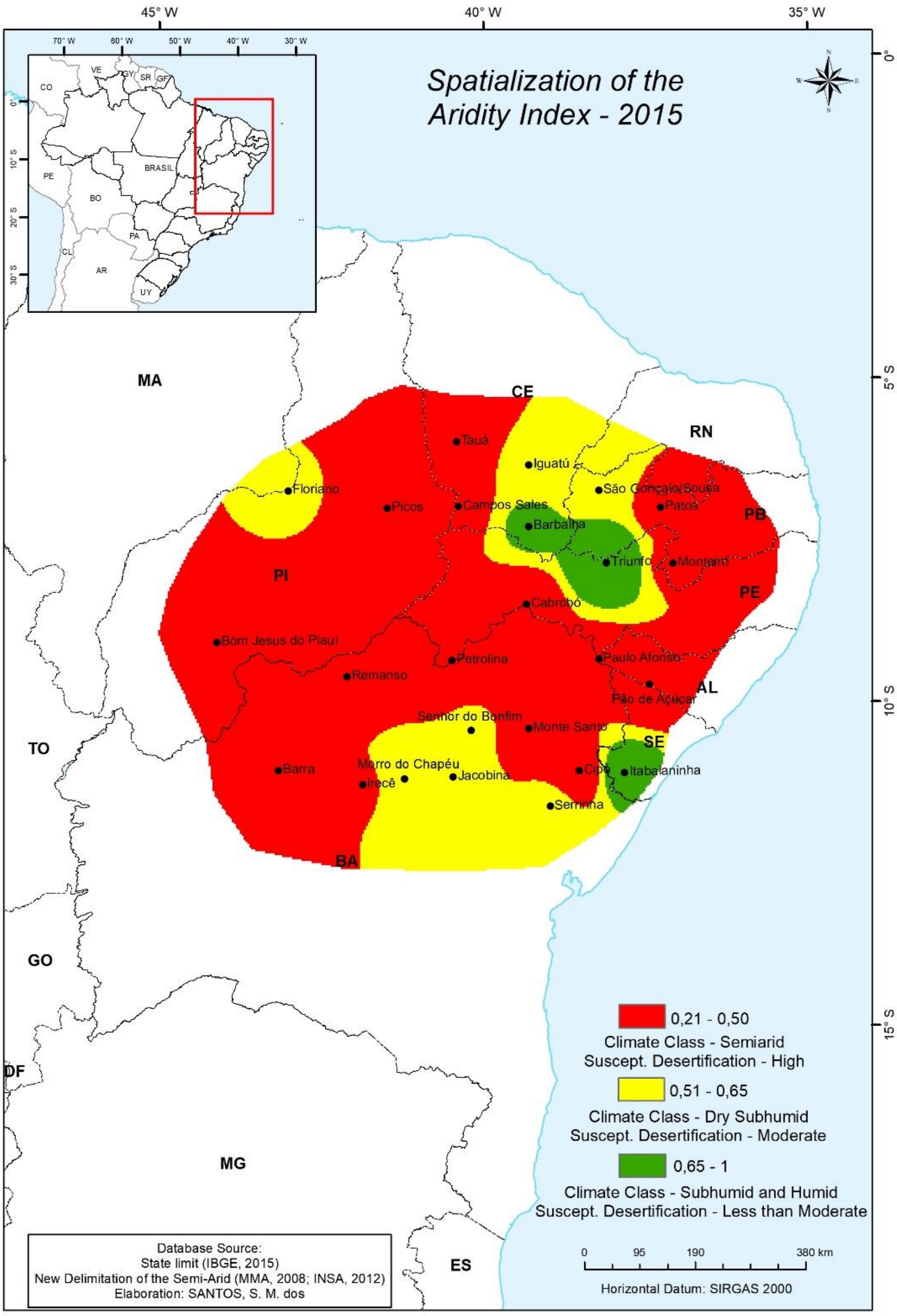

Figure 4 – Spatialization of series S2015 (data from 1985 to 2015), with the classification of desertification susceptibility to the year of 2015 with their respective histograms and statistical data.

Independently from the adopted period, it was verified a bigger part of the study area with high desertification susceptibility and a small portion with susceptibility inferior to moderate (Figure 2, Table 3). It was also possible to identify an evolution (between S2005 and S2015) from the areas with high desertification susceptibility (in red) verified through the advance to the west region of the state of Piauí and central part of Bahia and a reduction mainly of the areas with moderated (in yellow) and inferior to moderated (in green) desertification susceptibility among the three evaluated periods. These changes can be associated with the expansion of agricultural frontiers, and the portion west of the state of Piauí as in the region of the city of Bom Jesus do Piauí (Silva et al., 2014).

However, it is important to highlight that for these areas of classification inferior to moderated, it is observed two (2) phenomenon, an area is kept the same during the years, South region of Ceará, south east of Paraíba and center north of Pernambuco, as if in the south east region of the state of Sergipe.

When it also occurs the disappearing/elimination of a meaningful area in the central state of Bahia, region of Morro do Chapéu with a change of category of susceptibility to moderated. This change of AI in the central portion of the state of Bahia, a region of the city of Irecê, and it is noticed, with the meaningful loss of productions of main cultures of the region (Cunha, 2016).

Jatobá et al. (2017), in studies of climatic dynamics of semi-arid, specifically the region of Petrolina-PE, demonstrated a tendency to the increase of temperature during the period of 1961 and 2012 and a tendency to diminish the annual precipitation during the period from 1961 to 2012.

With the histograms results and the values of the descriptive statistic of interpolator selected to this job, it could observed that was generated a pattern deviation relatively low, approximately 0,10.

In a detailed way, in the three histograms, it is noticed that the apex and the values are closer to the apexes distributed among the categories semi-arid and sub humid dry, to the temporal series of 2005. To the sub sequent temporal series, 2010 and 2015, these apexes and higher values are more present in the semi-arid categories, values quantified in Table 3. This way, it reinforces one more time the connection of aridity conditions, as it was also observed by Lopes and Leal (2015), in which it was related to all the studied stations in the state of Bahia and Pernambuco that showed a reduction of AI to the period from 1961 to 2015.

Those results corroborated with an importance of making the accompanying of AI spatialization to the region which is the focus of this study, once that growth can result in fewer resources in an area that is climatically in deficit. It is worthy to highlight the present work that did not contemplate Brazilian Semi-arid region (SAB) as a whole, but a representative part of it.

Table 3 – Distribution of areas with desertification susceptibility to the temporal series 2005, 2010 and 2015 in km².

Desertification susceptibility	Period					
	1975 - 2005 (S2005)		1980 - 2010 (S2010)		1985 - 2015 (S2015)	
	(km²)	%	(km²)	%	(km²)	%
High	352.700	54	366.853	56	457.111	70
Moderated	252.900	39	244.853	38	158.711	25
Inferior to Moderated	43.967	7	37.861	6	33.744	5
Total area	649.567	100	649.567	100	649.567	100

In visualizing the space-time conditions in maps (Figure 2, 3 and 4) and in Table 3, it is highlighted an evident evolution in high desertification susceptibility areas, passing around 353 thousand km² in the period of temporal series 2005 to about 458 thousand km² in the period of 2015, an advance around 16% or approximately 105.000 km²

With the increase of conditions of a higher tendency to desertification, it also occurred a reduction of categories that have a lower possibility of desertification, but areas with moderated susceptibility to desertification passed diminished from 253 thousand km² to 159 thousand km² from 2005 to 2015, reduction of circa 14% or 94.000 km². Areas with susceptibility inferior to moderated reduced to 44 mil km² to 34 thousand km², recoiling around 2% or 10.000 km² in the period of temporal series between 2005 and 2015.

It is observed a bigger concentration of change between the periods of temporal series from 2010 to 2015 to the high susceptibility category (advance on the desertification condition), 14% or 91 thousand km² in comparison to the series from 2005 to 2010, 2% or 14 thousand km². As well as moderated susceptibility category (reduction of desertification conditions), 13% or 86 thousand km² between 2010 and 2015 and 1% or 8 thousand km²between the temporal series of 2005 and 2010.

4. Conclusions

The application of temporal series of 30 years with posterior spatialization allowed the observation of variation in aridity conditions in center-north of Brazilian semi-arid, with the tendency to the aridity conditions that means, with a reduction in the values of AI.

Space-time variation condition could be observed on maps and resulted in a perception of gradual temporal advance in areas with high desertification susceptibility and maintenance of areas with inferior to moderated susceptibility; these two conditions were possible because of the high reduction of areas with moderated tendency to desertification.

It was verified the necessity of deepening these studies using not only climatic variable, but also environmental variables, social and economic. It is suggested as a proposal of further work the use of spatial modeling to the relational analyses aiming a bigger range of desertification process to the Semi-arid.

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