Patterns of natural vegetation removal in the Caatinga biome in Prodes Project scope

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Abstract

The native vegetation removal (NVR) of Caatinga Brazilian biome has been mapped by Prodes Project coordinated by National Institute for Spatial Research (INPE) between 2000 to 2023 year. Prodes is considered an official government product for achieving Brazilian and international targets for the conservation of natural vegetation. Therefore, Prodes is committed to achieving the highest possible accuracy associated with the history of mapping already carried out, by visual interpretation of satellite images and the use of past mapping masks techniques. Mapping NVR in Caatinga biome is a major challenge compared to biomes where the tree canopy with native vegetation prevails. Caatinga is one of the least protected of Brazilian biomes and is in one of the most pressured semi-arid regions on the planet. This work aims to present the NVR in Caatinga biome from Prodes data, in terms of its trajectory and main geographical patterns, concerning the municipalities, and areas that are the focus of monitoring, conservation or restoration. According to Prodes results, by 2023, the cumulative NVR in the entire Caatinga reached 43,05%; in 2000, this figure was 29,54%. The major NVR occurred in the easternmost areas of Caatinga and regions of Serrinha and Feira de Santana in Bahia State. Also, there are areas with considerable NVR further inside the biome, such as, Irecê and Guanambi region in Bahia, west of Pernambuco and Paraíba States and South and North of Ceará State. Areas prioritized for conservation actions showed high NVR values, indicating the urgent need for implementation of such actions. The fact that Desertification Cores showed low NVR values is important, and these regions should be closely monitored to prevent uncontrolled NVR rates. The two regions with high anthropic pressure or speculation showed contrasting behaviors; while the Araripe Gypsum Pole exhibited higher NVR levels compared to the control area, the São Francisco River integration project (PISF) so far does not appear significantly different from the rest of the biome. Overall, this study clearly demonstrates the potential of monitoring the Caatinga through Prodes in understanding and integrating the various factors influencing changes in the biome's native vegetation cover. Future approaches should move beyond descriptive studies to increasingly contribute to the territorial management of this important Brazilian region.

1. Introduction

1.1 Prodes and Caatinga

The first official mapping by National Institute for Spatial Research (INPE) was carried out in the 1970s as a request of the Amazon Development Superintendence (Sudam), whose main objective was to verify whether the occupation of the territory was occurring as stimulated by official financing. With the advancement of environmental issues, the main motivation for satellite mapping was to estimate deforestation (native forest clear cut) rates to protect the forest (INPE, 2013).

Since 1988, INPE received from Brazilian Government the mission of developing and operating a system of monitoring to calculate annually the deforestation rate for the entire Brazilian Legal Amazon (BLA) through satellite images - Prodes Project[1]. The mapping was carried out on paper, scale 1:250,000 and a minimum mapping area of 6.25 hectares. From 2003 onwards, BLA mapping became digital, but some criteria were maintained to continue historical comparability: visual interpretation to prioritize accuracy, minimum mapping area at 6.5 hectares and incremental deforestation mapping (Almeida et al., 2021). Since Prodes digital, mapping was possible using different sensors and satellites that were being launched, such as the CBERS, IRS, DMC-2 series.

In 2003, at COP-9 in Milan, was presented the concept that developing countries are qualified to receive payments, as long as they show good results in reducing emissions and increasing forest carbon stocks (REDD[3]). In 2013, the Warsaw Framework (COP-19) implemented the REDD+ (adding sustainable forest management and the increase in forest carbon stocks) within the scope of the UNFCCC[2], which establishes the requirements for the recognition of forest loss mitigation results in developing countries, as well as the ways to obtain payments for these results (MMA, 2023).

The UNFCCC mandates that to be eligible for payments, developing countries must submit (i) a national strategy or plan, (ii) a national forest emissions reference level (FREL), (iii) a robust and transparent national system for monitoring and reporting on REDD+ activities (MRV – Measurement, Reporting and Verification) and (iv) an information system on the implementation of REDD+ safeguards (MMA, 2014). Prodes meets all these requirements for the BLA. In 2016, the mapping also included the Cerrado biome, whose FREL was approved in 2017 (MMA, 2017).

1 - Acronym for "Projeto de Monitoramento do Desmatamento na Amazônia Legal por Satélite"
2 - Acronym for United Nations Climate Change Conference
3 - Acronym for Reducing Emissions from Deforestation and Forest Degradation
4 - Natural vegetation removal identified as from prior years to the mapping reference year

In order to continue meeting the goals foreseen in the National Climate Change Policy (PNMC) and to meet the national REDD+[3], the Environmental Monitoring Program for Brazilian Biomes of Atlantic Forest, Caatinga, Pampa and Pantanal (PMABB) was designed by 2020 (Ordinance MMA 365/2015). Due the characteristics of some biomes cited, and their different phytophysiognomies, not only the clear cut forest should be mapped by any native vegetation removed by clear-cutting (NVR) should be included.

The NVR mapping of the Caatinga biome (Prodes Caatinga) was carried out until 2022 year by Funcate (Space Science, Applications and Technology Foundation), in a partnership with INPE. The Prodes Caatinga followed a similar methodology adopted to the Amazon and Cerrado, brazilian biomes that were already being monitored by Prodes (Almeida et al., 2019). However, some requirements were considered in Prodes Caatinga, such as, 1 hectare of minimum area mapped; adoption of Landsat series; selection of satellite images during the dry season of the region mapped, preferably within August, September and October, with the adoption of auxiliary images to avoid cloudiness in the primary image; false color band composition for visual interpretation (color/band): RED/NIR, GREEN/SWIR and BLUE/RED; classes used in the annual mapping (2017 onwards) were reservoir, cloud and relief shadow, deforestation residual[4] and deforestation in the year (Almeida et al., 2019).

The mapping for the year 2023 was carried out exclusively by INPE. Since then, some methodological adjustments were made in Caatinga mapping. The main ones were adapting the image acquisition calendar, including more months for acquisition, from July (the westernmost parts of the biome) to December (the easternmost parts of the biome); exclusive use of 20-meter Sentinel 2 satellite images; cloud detection by digital classification or vector edition assisted; expansion of bookmarks (reference communication between interpreters and reviewers), and; expansion of auxiliary data to solve interpretation misclassification issues and doubts, to mention: Planet Satellite images, radar images (Sentinel 1), Global Land Analysis & Discovery map products (https://glad.umd.edu/), hydrography and vegetation maps from IBGE (scale 1:250,000), digital terrain model from SRTM and Ecoregions maps (Velloso et al., 2001).

1.2 Caatinga issue

Caatinga has highly seasonal vegetation, presenting diverse phytophysiognomies ranging from Seasonally Dry Tropical Forests (SDTF) to sparse Shrublands and Savannas (Fernandes & Queiroz 2018). Therefore, Mapping NVR in Caatinga biome is a major challenge compared to biomes where the tree canopy prevails as native vegetation. Caatinga has major importance for biodiversity, whose floristic and phytophysiological variations are closely linked to soil and climate aspects. Its floristic diversity makes the Caatinga twice as rich as the Amazon rainforest when considering the species/area relationship (Fernandes et al., 2020). Moreover, Caatinga's 3,347 plant species, of which 526 are endemic, make it the most biodiverse area of SDTF in the Neotropics (the tropical New World biogeographic region comprising Central America, the Caribbean, and South America) (Fernandes et al., 2020).

However, this biome is one of the least protected of Brazilian biomes and is located in one of the most pressured semi-arid regions on the planet. It has only 8.8% of its area spared in Conservation Units (Brasil, 2000), being only 2.2% of Full Protection (Nogueira et al., 2024). Caatinga is considered one of the most densely populated dry lands on the planet (MMA, 2024), and has been associated for centuries with chronic human pressures, not always linked to deforestation, but rather to slow and progressive degradation.

Due to the importance, history of pressures and low protection situation of the Caatinga, this work aims to present the NVR in this biome from Prodes data, in terms of its trajectory and main geographical patterns, concerning the municipalities, and areas that are the focus of monitoring, conservation or restoration, such as, priority areas for biodiversity, desertification areas, and high pressure or speculation areas.

2. Methodology

The NVR was computed from the mapping class "deforestation in the year". In Prodes Caatinga the NVR was computed to the follow years 2000, 2004, 2006, 2008, 2010, 2011, 2014 and 2016 until 2023. For the other years without mapping, the NVR was calculated by interpolating the data from the years mentioned. In order to present a main geographical patterns of NVR distribution, we computed the NVR accumulated until 2023 and NVR rate between 2000 to 2023 for all municipalities with predominance of Caatinga biome, according IBGE (2024). In order to analyse areas of greater attention in relation to conservation and restoration, the NVR was generated and analysed for Priority Areas for Biodiversity (MMA, 2023) and for Desertification Cores (Perez-Marin et al., 2012).

The Priority Areas for biodiversity concerns a geographical analysis to meet conservation targets for fauna species and flora environments at the lowest possible cost (MMA, 2018) They are separated in Biological Importance and Action Priority Areas cotegories. The first one means the degree of importance of conservation, based on the following criteria: (i) existence of conservation targets already established; (ii) conservation goals for each target, and; (iii) cost of conservation. The second one indicates the degree of conservation measures, such as, management and restoration actions, research, environmental education, the creation of protected areas, institutional actions, and others (MMA, 2018). Given the criteria and targets of the two categories mentioned, it is assumed that certain areas are more irreplaceable than others, and in these cases these areas are called "extremely high" importance.

The Desertification Cores have susceptibility to desertification and are, generally, large bare patches, the presence or absence of undergrowth and clear signs of of soil erosion (Junior, 2001; Perez-Marin et al., 2012). They were formulated by Vasconcelos Sobrinho in the 1970s so that more in-depth studies could be conducted in these large areas, which were also recognized as pilot areas (Junior, 2001). These Cores were initially five and other studies over the decades have expanded and adapted these Cores (Perez-Marin et al., 2012).

And to focus on analyse NVR monitoring areas, we choice two large areas under high pressure or speculation, the São Francisco River integration project (PISF) and Araripe Gypsum Pole. The first refers the transposition of water from the São Francisco River to the northernmost regions of the Northeast brazilian region. The PISF's NVR was calculated under an influence area around the sections whose installation of the project was completed. They are the northern axis and the eastern axis plus their associated canal, called Ramal do Agreste (RAG). We consider a buffer of 5 km around these axis, excluding the areas with permission to suppress vegetation (PSV) which were defined during the environmental licensing process, according

Coelho et al. (2020). The PISF's Installation Licenses date back to 2007 for the East and North Transposition Axis, and the operating licenses to 2018 and 2022 for the East and North Axis, respectively. The RAG obtained its Installation License in 2016 and has not yet received the operating license.

While Araripe Gypsum Pole is in the western part of the state of Pernambuco, the Araripe Region of Pernambuco, which is made up of the following municipalities: Araripina, Bodocó, Exu, Granito, Ipubi, Moreilândia, Ouricuri, Santa Cruz, Santa Filomena and Trindade. Four them comprises the Local Productive Arrangement (APL), called as Araripe Gypsum Pole: Araripina, Bodocó, Ipubi, Ouricuri e Trindade (Lima et al.; 2020; Santos et al., 2023). For this study, we adopted a larger area of influence, so that we adopted the Araripe Region of Pernambuco as Araripe Gypsum Pole. Unlike PISF, mining activities in the Araripe Gypsum Pole span more than 50 years, beginning in the early 1960s (Santos et la., 2023). This region has historically suffered from anthropogenic pressure on its vegetation cover due to the need to exploit firewood for the gypsum calcination process (Silva, 2008). The Figure 1 presents a map with the Caatinga limit, the predominant municipalities and the four layers of analysis.

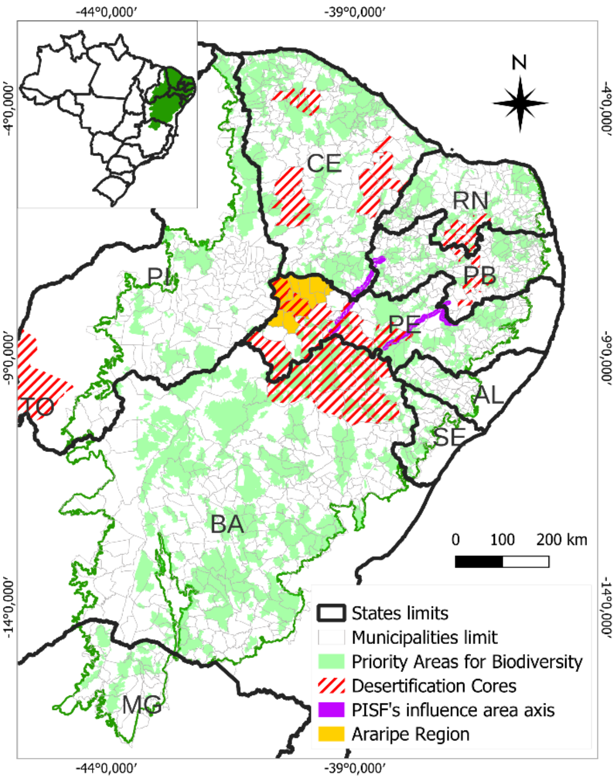

Figure 1 – Caatinga limit with the layers to NVR analysis

In all the situations mentioned above, except for the NVR for municipalities, the NVR was calculated outside the areas of interest in the Caatinga biome – called here a Control Areas - in order to have a reference for comparison with the rest of the biome.

3. Results

According to the Prodes results, the entire Caatinga has reached 43,05% of cumulative NVR in 2023 (371.387,78 km²), in 2000 this figure was 29,54 % (254.859,44 km²), considering that the potential area for deforestation in the Caatinga was calculated at 862.639,52 km². According Terrabrasilis website (Assis et al., 2019), the highest NVR per year was up to 2007 year, with more than 6,4 km² per year, the lowest NVR per year were between 2014 and 2021 years, around 2 km² per year.

The Figure 2 presents the geographical distribution of NVR accumulated until 2023 year and the Figure 3 the proportional NVR increase between 2000 and 2023 years, along the predominant municipalities of Caatinga. The major NVR occurred in the easternmost areas of Caatinga and regions of Serrinha and Feira de Santana in Bahia State. Also, there are areas with considerable NVR further inside the biome, such as, Irecê and Guanambi region in Bahia, west of Pernambuco and Paraíba States and South and Northe of Ceará State. Concerning proportion of NVR increase, the pattern is closed to the NVR accumulated, but it looks like more concentred; Rio Grande do Norte State, South of Ceará and West of Paraíba States have greater enhance in relation to the NVR accumulated.

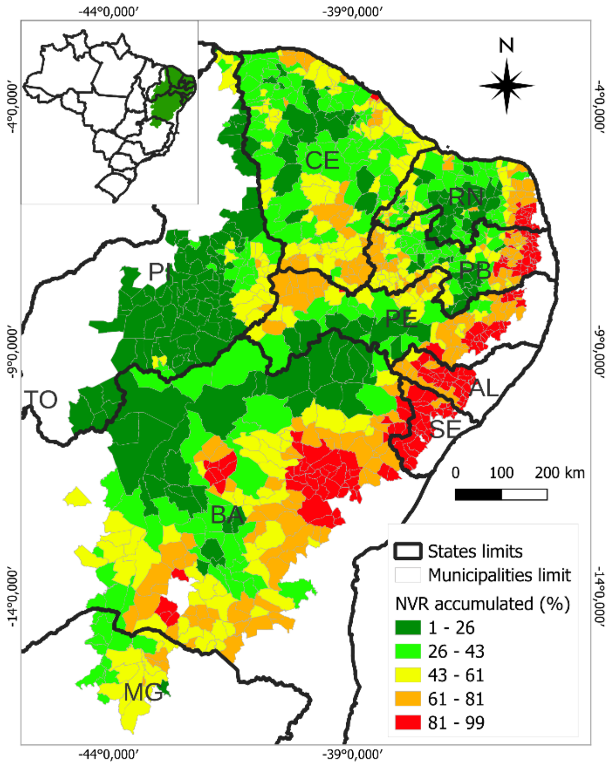

Figure 2. Distribution of NVR accumulated in Caatinga municipalities until 2023 year by Jenks natural breaks

The Table 1 presents the ranking of the ten municipalities with the highest NRV accumulated and proportional NVR increase between 2000 to 2023 years. And Table 2 presents the ranking of the ten municipalities with the lowest NRV accumulated and proportional NVR increase between 2000 to 2023 years. Both of tables presents the Federation Unit (F.U.) acronym that each municipality belongs. Most of the 10 municipalities with the highest NVR accumulated are in the state of Alagoas (AL), while the most of the 10 municipalities with the highest proportional NVR increase is in Rio Grande do Norte State (RN). Concerning the ten municipalities with lowest NVR, the Piauí State (PI) has the most municipalities with the lowest NVR accumulated, and Bahia State (BA) has the most municipalities with the lowest proportion of NVR increase. These municipalities are located in the southeast of Piauí and the north of Bahia states.

Especially noteworthy is none of the ten municipalities with highest NVR accumulated are the same of the ten municipalities with highest proportion of NVR increase. Furthermore, the ten municipalities with the highest cumulative NVR have more than 97% of their territory converted, which is quite a contrast to the 10 municipalities with the lowest cumulative NVR, less than 6% of their territory. Concerning to the proportion of NVR increase, this contrast is also evident, but it is not so high. It is important to note that among the ten municipalities with the lowest proportion of NVR increase, most of them are also ranked as having the lowest NVR accumulated. This pattern does not happen with the highest NVR municipalities.

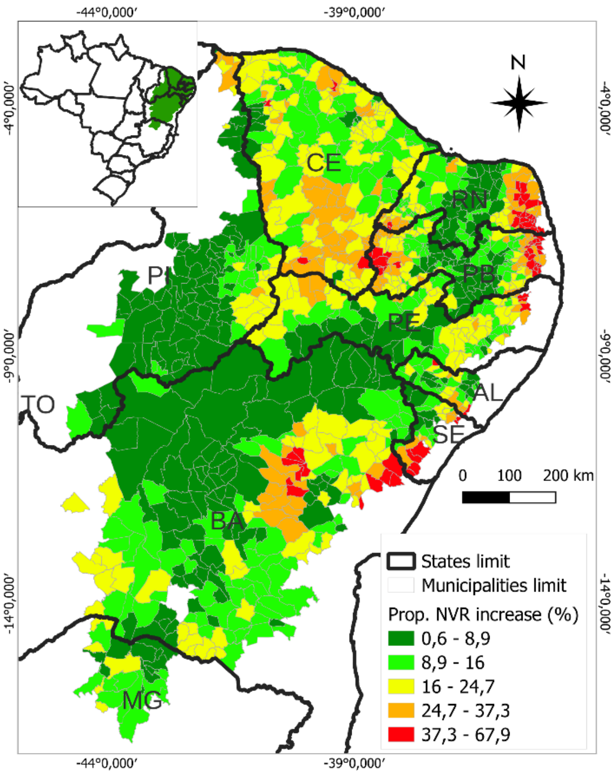

Figure 3. Distribution of proportional NVR increase between 2000 and 2023 years in Caatinga municipalities by Jenk natural breaks

Highest NVR accumulated ranking			**Highest proportional NVR increase ranking**		
Ranking	**Municipality and F.U.**	**%**	**Ranking**	**Municipality**	**%**
1º	Taquarana (AL)	99,28 %	1º	Várzea (RN)	67,93 %
2º	Santa Bárbara (BA)	98,98 %	2º	Jundiá (RN)	67,89 %
3º	Agrestina (PE)	98,84 %	3º	Cuité de Mamanguape (PB)	63,57 %
4º	Lagoa da Canoa (AL)	98,79 %	4º	Passagem (RN)	58,07 %
5º	Palmeira dos Índios (AL)	98,04 %	5º	Santo Antônio (RN)	56,42 %
6º	Cupira (PE)	98,02 %	6º	Lagoa d'Anta (RN)	56,04 %
7º	Nova Fátima (BA)	98,00 %	7º	Ielmo Marinho (RN)	53,59 %
8º	Itabaiana (PB)	97,98 %	8º	Várzea do Poço (BA)	53,07 %
9º	São Joaquim do Monte (PE)	97,90 %	9º	Alagoinha (PB)	52,87 %
10º	Arapiraca (AL)	97,82 %	10º	Riachão do Poço (PB)	52,79 %

Table 1 – Ranking of the ten municipalities with the highest NVR, accumulated and rate.

Lowest NVR accumulated ranking			**Lowest proportional NVR increase ranking**		
Ranking	**Municipality and F.U.**	**%**	**Ranking**	**Municipality**	**%**
1º	Canavieira (PI)	0,88 %	1º	Macururé (BA)	0,59 %
2º	Guaribas (PI)	2,62 %	2º	Chorrochó (BA)	0,72 %
3º	Tamboril do Piauí (PI)	3,71 %	3º	Canavieira (PI)	0,76 %
4º	Chorrochó (BA)	3,90 %	4º	Guaribas (PI)	1,07 %
5º	Macururé (BA)	3,99 %	5º	Coronel José Dias (PI)	1,14 %
6º	Ilha Grande (PI)	4,64 %	6º	Lapão (BA)	1,45 %
7º	João Costa (PI)	4,74 %	7º	Tamboril do Piauí (PI)	1,64 %
8º	Curaçá (BA)	5,20 %	8º	Presidente Dutra (BA)	1,66 %
9º	Coronel José Dias (PI)	5,25 %	9º	Curaçá (BA)	1,73 %
10º	Dom Inocêncio (PI)	5,94 %	10º	Sento Sé (BA)	1,74 %

Table 2 - Ranking of the ten municipalities with the lowest NVR, accumulated and rate.

The Figures 4 and 5 presents the NVR in Priority Areas for Biodiversity has been computed, for the Biological Importance and Action Priority categories in their three classes (extremely high, very high and high). Comparing the NVR between categories of Biological Importance and Action Priority, the second one presents greater classes proportional differences than the first one. It means that NVR is more sensitive to the social, economic, and environmental costs associated with the implementation of conservation actions, than to strictly biological and ecological differences.

The classes of Biological Importance presents less NVR than the rest of Caatinga – Control area –, which is a desire pattern. While NVR in Action Priority areas, the Extremely High class is higher than the Control area. In both categories, the most sensitive classes are associated with a higher NVR, however in Action Priority areas this association is even more pronounced. The major NVR increments are between 2000 to 2008.

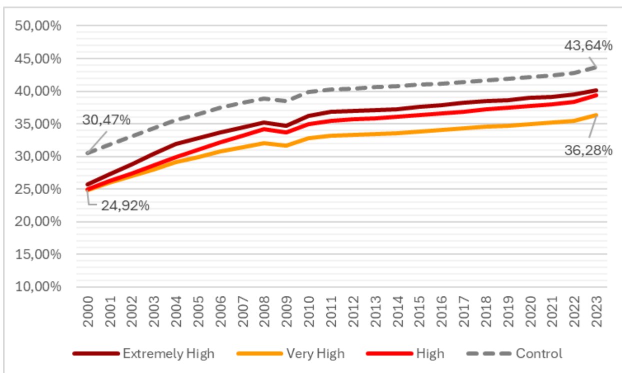

Figure 4. NVR in Biological Importance areas

The Figure 6 presents the NVR accumulated in Desertification Cores, comparing to the Control area. Is curious see a lower NVR in Desertification Cores with a higher NVR than the rest do Caatinga – Control area. A noteworthy aspect is the NVR means a clear cut of native vegetation, which is associated for some conversion of land use. Lands with low land productivity requires greater investment to convert to agriculture or pasture uses, in order to become a productive land again. This does not mean that these lands are not being used for any purpose. On the contrary, in the Caatinga there are many uses that are consorted with the vegetation, with less demand on the vegetation and less impact on it. This is the case of the silvopastoral use of goats in the north of Bahia State with the use of common areas on private properties (*Fundo de Pasto* way). In this case there is no removal of native vegetation. However, in these areas there may be a slow process of land degradation, which is not the aim of Prodes Caatinga so far.

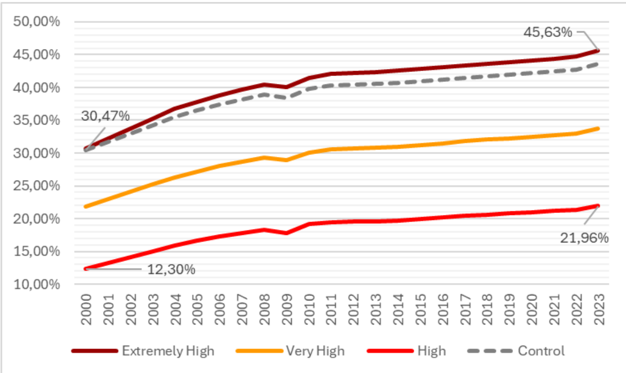

Figure 5. NVR in Action Priority areas.

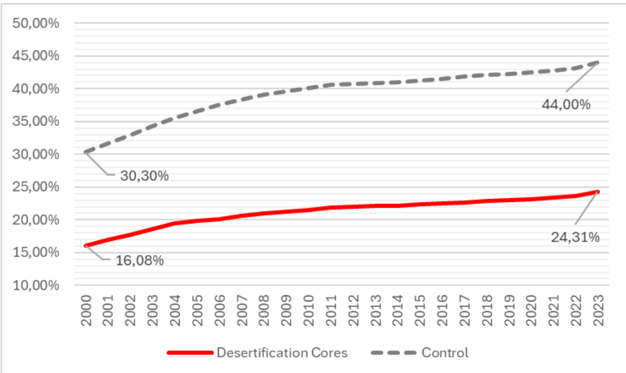

Figure 6. Desertification cores

The Figure 7 presents the NVR accumulated in PISF influence area and the Control area. There is very little difference between the two NVR patterns. If a significance test were to be carried out comparing these patterns, it would probably be significantly the same. However, in the period around the first half of the 2000s there was a noticeable increase in NVR in the areas of influence of the PISF, which refers to a period of Pre-Installation Licenses, but it decreases along the next years.

The Figure 8 presents the NVR accumulated in Araripe Gypsum Pole and the Control area. There is a great difference in NVR accumulated in the Araripe Gypsum Pole in relation to the rest of Caatinga. This pattern is consistent with the type of use of the region, pasture and extraction of firewood for calcination. It is important to emphasize this result does not necessarily mean that there is little vegetation cover in the Araripe Gypsum Pole. Lately, the use of forest management with exotic species for the purpose of using firewood has been expanded. However, for biodiversity and conservation purposes, the region the region needs attention for restoration.

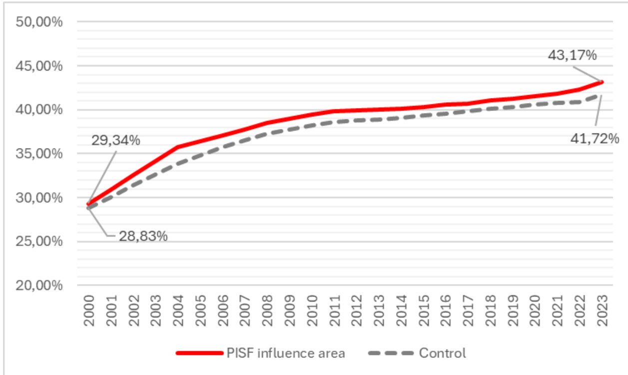

Figure 7. NVR in PISF influence area.

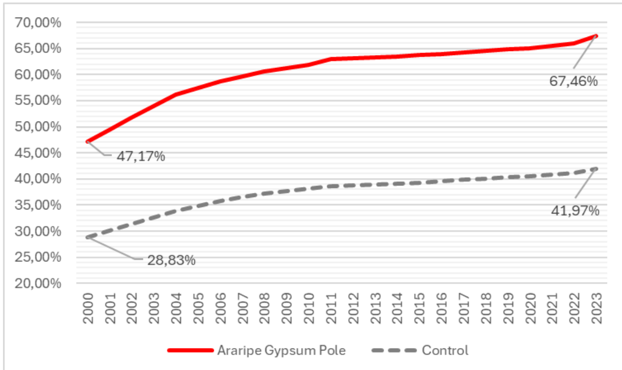

Figure 8. NVR in Araripe Gypsum Pole.

In all the cases presented at the figures above, it is important to note that the 2023's NVR increment presented a somewhat unusual increase, in relation to the historical NVR trend. This is due to the methodological change employed in the year 2023, especially in relation to the longer time window of images for interpretation, performing images with fewer clouds, and the change from the Landsat TM/OLI sensor to the Sentinel MSI, implying a change in spatial resolution from 30 to 20 meters.

4. Discussion

In relation to the accumulated and proportion increases of NVR in the municipalities, it is important to note that many of these may have a percentage of Caatinga close to 50%, so high values do not mean that the entire municipality is almost devoid of native vegetation.

The geographical patterns of NVR are coupled with some distribution patterns of cattle herds, based on IBGE surveys for the years 2000 and 2022, which are an important vector for NVR and a relevant source of pressure on the native vegetation of the Caatinga (Araujo et al., 2023). Otherwise, on the concentration areas of sheep and goat herds the NVR does not occur preferentially, which denotes that the usual pattern of this type of activity, at least in certain areas, is silvopastoral use, which there is no removal of natural vegetation. However, these activities have reasonable coupling with the areas of Desertification Cores.

The possibility of cross-evaluating this kind of information must be continually analyzed to assess how patterns of NVR in Caatinga are related to one of the main vocations of this biome, the livestock farming.

The fact that this study did not identify notable differences between the NVR pattern in PISF influence area in relation to the Control area corroborates with Coelho et. al (2020) study, which they analysed the NVR during the installation period of the Eastern axis. Reinforcing the finding that the impacts of this extensive linear infrastructure on the loss of vegetation did not exceed the areas directly designated for this purpose. However, the indirect areas of influence of this kind of infrastructure should be evaluated to NVR analysis.

Such results reinforce the need for more studies that present specificities of each case presented. An important piece of data for this type of analysis is the mapping of degraded areas, which would provide another look at the Desertification Nuclei.

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