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THE LAGOONS OF ALAGOAS IN THE *CAATINGA* BIOME: DETECTION, ANALYSIS AND TEMPORAL MAPPING WITHIN THE CONTEXT OF CLIMATE CHANGE

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ABSTRACT

This research aims to map and evaluate the dynamics of surface water bodies in the *caatinga* biome in Alagoas in Northeast Brazil, from 1987 to 2017, using remote sensing data. Hydrography was considered an important element in the history, culture, economy and landscape in the State of Alagoas, whose toponymy originates from the numerous lagoons that are distributed throughout the territory. Using temporal satellite images and own methodology to process these images, existence of three groups of polygons that mapped the lagoons and dams of that period were detect. Although the balance had been positive, in 1987 2,003 polygons were detected and in 2017, 3,133, it is highlighted the disappearance of 1,349 ponds/weirs, most of them smaller than 1 hectare. Taking into account the serious impact on the weir system in the *sertão*, tracks were sought to elucidate its causes. For this, a field validation was defined for seven water bodies selected in five municipalities in the region, showing a heterogeneity of reasons for the decreases in the surface water, or even their disappearances, including climate change. As a result, a complex social and environmental picture that requires immediate action from the government and society to mitigate the impacts of climate change was revealed.

Keywords: Surface water bodies. Climate impacts. *Caatinga*. Alagoas.

AS LAGOAS DE ALAGOAS NO BIOMA *CAATINGA*: DETECÇÃO, ANÁLISE E MAPEAMENTO TEMPORAL NO CONTEXTO DAS MUDANÇAS CLIMÁTICAS

RESUMO

O objetivo desta pesquisa foi mapear e avaliar a dinâmica dos corpos hídricos superficiais do bioma *caatinga* em Alagoas no Nordeste brasileiro, no período de 1987 a 2017, a partir de dados de sensoriamento remoto. Considerou-se a hidrografia um elemento importante na história, cultura, economia e paisagem no Estado, cuja toponímia tem origem nas numerosas lagoas que se distribuem pelo território. Por meio de imagens temporais de satélites, utilizou-se de metodologia própria para processar essas imagens e detectar a existência de três grupos de polígonos que mapearam as lagoas e açudes desse período. Embora o balanço seja positivo, em 1987 foram detectados 2.003 polígonos e, em 2017, 3.133, preocupou o desaparecimento de 1.349 lagoas/açudes, a maioria menores que 1 hectare. Considerando tratar-se de impacto grave ao sistema de açudagem no sertão, buscou-se pistas para elucidar suas causas. Para tanto, uma validação de campo amostral foi definida para sete corpos hídricos selecionados em cinco municípios da região, revelando uma heterogeneidade de razões para as diminuições de espelho d'água, ou mesmo seus desaparecimentos, inclusive as mudanças climáticas. A pesquisa revelou um quadro social e ambiental complexo que exige do governo e da sociedade, ações imediatas de mitigação aos impactos das mudanças climáticas.

Palavras-chave: Corpos hídricos superficiais. Impactos Climáticos. *Caatinga*. Alagoas.

INTRODUCTION

Environmental changes and their impacts on natural systems and human societies include multidisciplinary segments of scientific research. Surface water is among the most vital earth resources undergoing changes in time and space as a consequence of land use/cover (LULC) changes, climate change and other forms of environmental changes in many parts of the world (FEYISA *et al*., 2014).

The Brazilian case presented in this article deals with the environmentally impacted *caatinga* biome, which virtually coincides with the delimitation of the Brazilian semiarid region, extending to all States of the Northeast, except Maranhão, reaching up to the North of Minas Gerais (MMA, 2010).

The *caatinga* is regarded as one of the cores of the seasonally dry tropical forests, whose current remainders are concentrated mainly in the Neotropics (MURPHY and LUGO 1986; PENNINGTON *et al*., 2006, *apud* BARBOSA *et al.,* 2013). This core goes through at least eight months of dry each year and receives no more than 1,000 mm/year of precipitation (RODAL *et al*., 2008, *apud* BARBOSA *et al.,* 2013).

Deforestation of the *caatinga*, fragility of the soils, and climate change are important parameters for the environmental management of drainage basins, in the sense of being able to plan preventive actions in the areas susceptible to desertification, as well as in the recuperation and rehabilitation of degraded and desertified areas (GARCIA *et al*., 2019).

The rivers in the *caatinga* are, in their great majority, intermittent, drying up during prolonged dry spells. Many of these rivers, however, had stretches that were artificially perennialized through the construction of weirs, which are, together with the temporary ponds, the main aquatic habitats in the region (BARBOSA *et al.*, 2013).

Anthropic activities on the *caatinga*, related to the removal of riparian vegetation and pollution of watercourses by the production activities, with pesticides, as well as the inadequate handling of the herd and the extraction of wood are among the causes of the increase in the degradation of this biome (COSTA *et al.,* 2009).

In Alagoas, a case study in this article, the portion of the *caatinga* biome, that covers virtually half of the area of the State and is located in a semi-arid region, is characterized by a superficial water network composed of, essentially, temporary or intermittent rivers and streams due to the rainfall deficit. In other words, only in rainy periods these bodies have enough surface water volume to generate a river flow, which characterizes an aquatic transition system (BARBOSA *et al*., 2019). In the semi-arid region, these periods occur between the months of June and September and are characterized by irregular, convective, and intermittent precipitation. However, it is important to highlight that such region is also characterized by consecutive dry spells and prolonged droughts. Therefore, the superficial availability of surface water is scarce and crucial for the survival of numerous populations that inhabit the semi-arid region of Alagoas.

Paradoxically, the several rivers, streams, creeks, weirs, dams, ponds, and lagoons are important elements of the landscape, economy, culture, and history of the State of Alagoas. In this regard, Queiroz (1999) states that the several ponds (*lagoas*) in our land led the first settlers to name it Alagoas. Thus, this aspect of the hydrography of Alagoas defines, to date, the name of the State". The ponds that inspired the name of the State are distributed in three types of landscapes: 1) coastline ponds, where stand out Mundaú, Manguaba, and Jequiá; 2) ponds on the banks of the São Francisco River, such as Tororó, Santiago, and Jacobina, among others; and 3) inland ponds, for example, Porcos, Canto, and Nova Lunga (ALAGOAS, 2020). The largest surface inland bodies of water are located in estuarine environments on the coast of Alagoas: the majestic Mundaú and Manguaba ponds, both close to the capital Maceió, and the Jequiá Pond, on the south coast, in addition to several other ponds, rivers, and perennial and intermittent streams that rise in the semi-arid, *agreste*, and *zona da mata* regions, many of which flow into the coastline, while others are affluents of the drainage basins in the State.

In this semi-arid region, the most important exception to the intermittency of rivers and streams is the São Francisco River, constituting the greatest drainage basin of the State (and one of the greatest in the country).

The São Francisco River's headwaters are located in Serra da Canastra, in Minas Gerais, and have an approximate length of 2,700 km to its mouth in the Atlantic Ocean, between the States of Alagoas and Sergipe. While going through the State boundary between Sergipe and Alagoas, the São Francisco River has part of its long-left bank in the semi-arid region of Alagoas, being the most important water resource of this region.

With regard to remote sensing techniques, in recent decades, they have undergone a great evolution from the emergence of modern sensor, aerial, and orbital systems capable of producing multispectral and hyperspectral images of high spatial, temporal, and radiometric resolutions, increasing the ever-better ability to differentiate the targets of the terrestrial surface, significantly expanding the applications related to the study of the land use and occupancy patterns (ASSIS, 2020). In parallel to the evolution of remote sensing data acquisition systems, new methodological approaches to digital image processing have emerged, thus optimizing the information extraction in order to monitor the terrestrial surface. Some recent studies of remote sensing have been directed at monitoring the vegetation cover of the *caatinga* biome (BEZERRA *et al.,* 2014; VIEIRA *et al*., 2015; OLIVEIRA *et al*., 2017; BARBOSA *et al*., 2018). Several studies conducted over the last few years have been focused on mapping and analysis of aquatic systems based on remote sensing data (BARBOSA *et al*., 2019). Pressures on water resources and disaster management are rising primarily due to the unequal spatial and temporal distribution of water resources and pollution, and also partially due to our poor knowledge about the distribution of water resources and poor management of their usage (WANG and XIE, 2018). Wang and Xie (2018) present important review on Applications of Remote Sensing and Geographic Information Systems (GIS) in Water Resources and Flood Risk Management.

The spectral effects of optically active components (COAs) on water reflectance have been widely discussed in the literature (PEREIRA *et al.*, 2011; LE *et al*., 2013; LOPES *et al*., 2014). Feyisa *et al*. (2014) using Landsat 5 TM data, introduced a new automated method of water extraction. The study significantly improved accuracy in areas where shadows and other dark surfaces were the main sources of classification errors.

In this context, this research aimed to map and assess the dynamics of surface water bodies in the area of the *caatinga* biome in Alagoas during a recent period of 30 years (from 1987 to 2017) based on remote sensing and meteorological data.

ASPECTS OF THE STUDY AREA

The semi-arid region of Alagoas is characterized by an average annual rainfall inferior to 800 millimeters, aridity index of up to 0.5, and drought risk higher than 60%. In this region, the vegetation is under the *caatinga* domain and the average temperatures range from 17°C to 33°C (BARROS *et al.,* 2012).

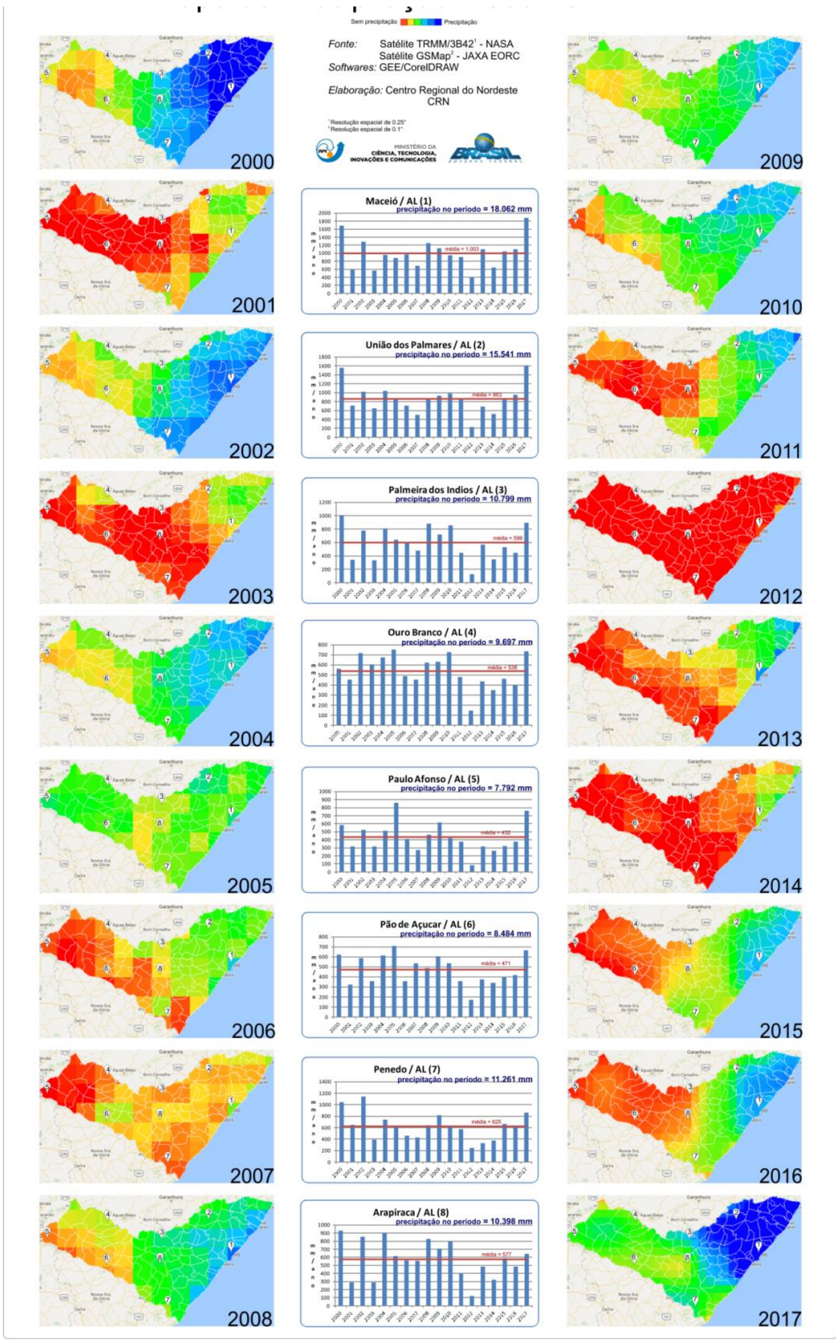
The soils are predominantly shallow and rocky, rich in minerals, but poor in organic matter. The soils of the region are Litolics and Regolithic Neosols, originating from the Granitoid complex, the base formation of the Sertaneja Depression. However, in the municipalities of Olho D'Água do Casado and Delmiro Golveia, the soils are Quartzarenic Neosols with a sedimentary base, from the Paleozoic Sandstone, which forms an island around the Granitoid Complex. These soils are shallow, coming from physical weathering, registered by the daily thermal amplitude and low rainfall. The most notable exceptions are the "brejos de altitude", which are located in the municipalities of Mata Grande and Água Branca, located in the orographic position to windward, on the Borborema Plateau. These areas record Atlantic Rainforest vegetation, contrasting with the surroundings of *Caatinga*, which permeate the Sertaneja Depression in Northeast Brazil (ASSIS, 2020; JATOBÁ *et al.,* 2019; TABARELLI *et al.,* 2017) that permeate the backlands, *sertão*, of the Northeast of Brazil and, by receiving the humidity of the east winds, enable the development of a humid tropical flora of significant size and biomass. The geographic distribution of soils in the state of Alagoas, prior to the Brazilian Soil Classification System, can be accessed on the website: http://geoinfo.cnps.embrapa.br/layers/geonode%3Asolos_al_geogr_wgs84. Accessed on: 11/11/2021. Other references on soils are available from: SANTOS, H. G. *et al*. Sistema Brasileiro de Classificação de Solos. 3a. ed. Rio de Janeiro, Embrapa Solos, 2013a. 353 p.

In spite of being located in a semi-arid region, the *caatinga* biome in Alagoas presents numerous natural or man-made reflecting pools, as well as rivers, streams, and temporary and intermittent creeks that are distributed in this territory. These water resources are of fundamental importance to support the economic activities in extensive and varied production chains, but also to the survival of a significant portion of the population living in the semi-arid region.

This importance becomes even more relevant especially when it is taken into consideration that such region comprises about 44% of the total area of Alagoas (27,778.506 km²), *i.e.,* 12,788 km² (IBGE, 2020), being marked by historical shortage, inaccessibility, and poor water distribution. In this scenario, climate change will certainly worsen the water crises already installed and aggravate the social vulnerability situations in the region. The low annual rainfall in the region ranges from 300 to 800 mm (INPE, 2002), quite lower than what was verified in the coastline, which varies from 1,100 and 1,800 mm – which makes the access to water a decisive and strategic factor for the populations of the backlands in general and, more specially, for significant portions of higher social vulnerability in the region. In Figure 1, it is possible to identify the evolution of the average rainfalls through maps and data from 2000 to 2017 in Alagoas.

From this reading, it becomes evident the differentiation of the rainfall in the regions of the State, which establishes natural conditions for agropastoral and subsistence activities, among other factors. While the humid coastal areas are essentially characterized, from the economic point of view, by the secular sugarcane monoculture, the interior of the backlands is marked by the subsistence, dry farming, and extensive pasture. The *agreste* region, as a transition zone, presents intermediate values, both for rainfall and average temperatures verified between the coastline and the *sertão*.

Figure 1 - Rainfall in Alagoas from 2000 to 2017.



Source - INPE (2020).

Therefore, mapping and assessing these bodies of water are strategic actions for the survival of these backland's populations, especially with regard to climate change and how these changes can be affecting the availability, capacity, and dynamics of these water resources in the *caatinga* region, combined with different anthropic factors, such as: deforestation, pollution, irrigation, etc.

Consequently, reaffirming the importance of water resources for these populations within the context of global climate change, the objective of this work was to assess the dynamics of the main surface water bodies in the area of the *caatinga* biome in Alagoas over the last 30 years, from satellite images in time series that ensured the coverage of the entire of the *caatinga* biome area in Alagoas.

A methodology was defined for this mapping based on Remote Sensing Digital Image Processing (DIP) techniques, using raw images with free access in specific websites, adjusted and processed in software dedicated to this type of georeferenced data. Subsequently, the desk works were validated through field researches, in selected locations, according to what is described below.

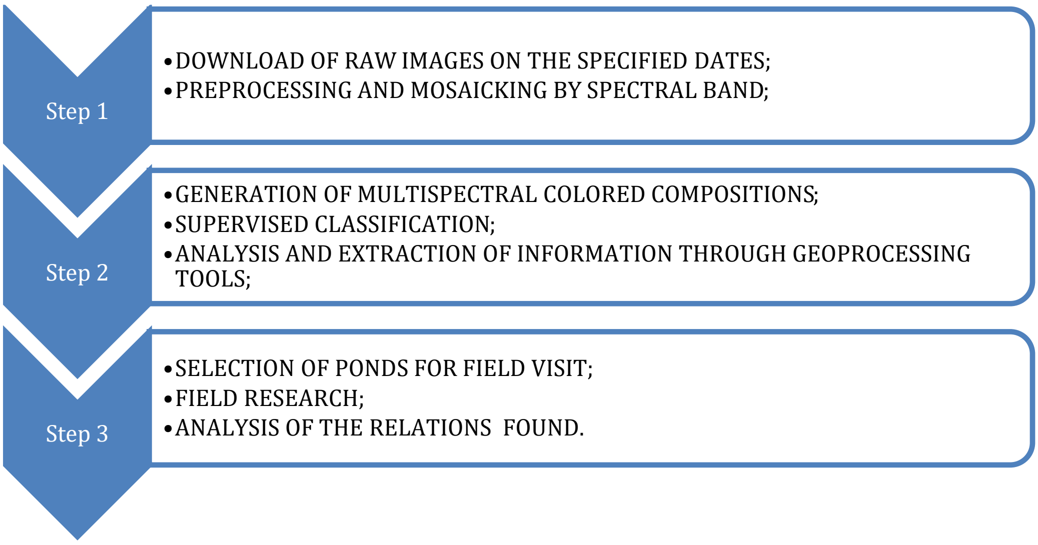
MATERIALS AND METHODS

The materials used in this study involved multispectral and temporal images of the LANDSAT-5/TM and LANDSAT-8/OLI satellites and the QGIS 2.18.26 and Spring 5.5.5 software.

The methodological procedures involved different remote sensing and digital image processing, supported by the theoretical basis of the following references: INPE (2002); Jensen and Garcíaquijano (2005); Lillesand *et al.* (2008); Meneses and Almeida (2012).

The flowchart of the methodology used to map the surface bodies of water from satellite images with the corresponding steps and activities are described in Figure 2. In the process of extraction of information about the existing ponds, the first step was the identification and acquisition of satellite images of the study area. The acquisition of such data consisted of the download of the historical series of LANDSAT Images, TM and OLI sensors based on the United States Geological Survey – USGS image catalog, available at https://earthexplorer.usgs.gov/.

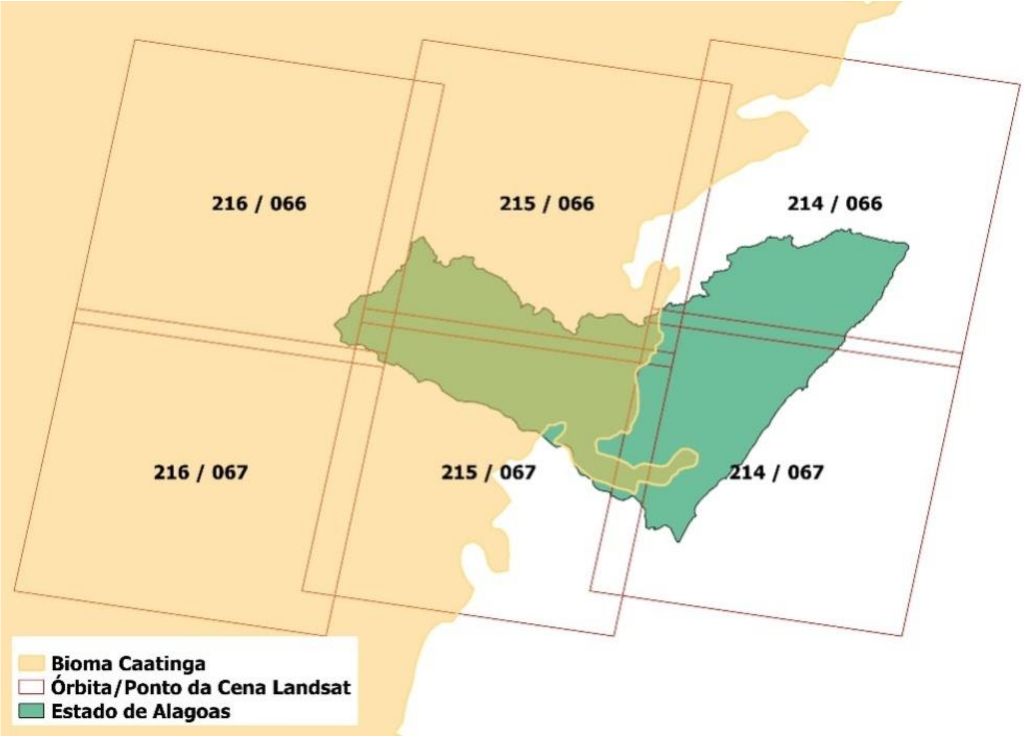
Figure 2 - Flowchart of the methodological steps of the surface bodies of water mapping.



Source - Authors (2019).

The years of 1987 and 2017 were used as research criteria, always in the periods from December to February (which refers to the drought period of the region), in addition to orbit/point of scenes that fully covered the State of Alagoas, such scenes being the 214/066, 214/067, 215/066, 215/067, 216/066, and 216/067 scenes, as shown in Figure 3.

Figure 3 - Landsat scenes grid scheme for the State of Alagoas.



Source - Authors (2019), from USGS data.

As the study is limited to the *caatinga* biome area, only four scenes were necessary (215/066, 215/067, 216/066, 216/067) to cover the biome area delimited by the State of Alagoas. Nonetheless, as seen in Figure 3, a small portion of the biome is not covered by these scenes and, for this reason, was excluded from the study area. The four scenes concerned were selected with the verification of the smallest cloud coverage and are presented in chart 1. The best scenes selected are from the years of 1987 and 2017, which comprises a period of 30 years. This period is the minimum recommended that should be used for studies on climate change (IPCC, 2019).

Chart 1 - Orbital Landsat scenes selected for the research.

SCENES	TM/LANDSAT-5	OLI/LANDSAT-8
215/066	1/17/1987	12/5/2017
215/067	1/17/1987	12/5/2017
216/066	12/10/1987	12/12/2017
216/067	12/10/1987	12/12/2017

Source - Authors (2020), based on USGS (2019).

Using the QGIS 2.18.26 software, mosaics were created by scenes and false color compositions RGB543 (for the TM image mosaic) and RGB654 (for the OLI image mosaic) were made. These multispectral combinations allow a better visual acuity aiming at the next stage, the supervised classification.

For identification of surface water bodies, the Spring 5.5.5 software was used to do a supervised classification of Maximum Likelihood with a 99% acceptance threshold, processing the three spectral bands of the colored compositions mentioned, simultaneously. The main class sampled was the bodies of water, with other classes defined as "exposed soil", "urban area", "vegetation" and "clouds". The classifications performed 91% and 93%, respectively, for the mosaics of the images from 1987 and 2017.

The classified images were exported in GeoTiff format and the polygons classified as "water" were extracted from them through the polygonization method, using the QGIS software. Due to the class confusion between water and cloud shadows existing in the classification, it was necessary to "clean up" the classification result. This verification was performed using a true-color composite image where the polygons misclassified as water were manually excluded from the results.

From all classified polygons, seven were selected for field visitation. Despite the small number of features, this choice aimed to cover a variety of situations, such as: disappearance, appearance, and variation of water bodies, in addition to avoiding the errors associated with supervised classification. Thus, the classification was intended to select the best candidate water bodies for field visitation.

RESULTS AND DISCUSSION

Balance of the mapped areas

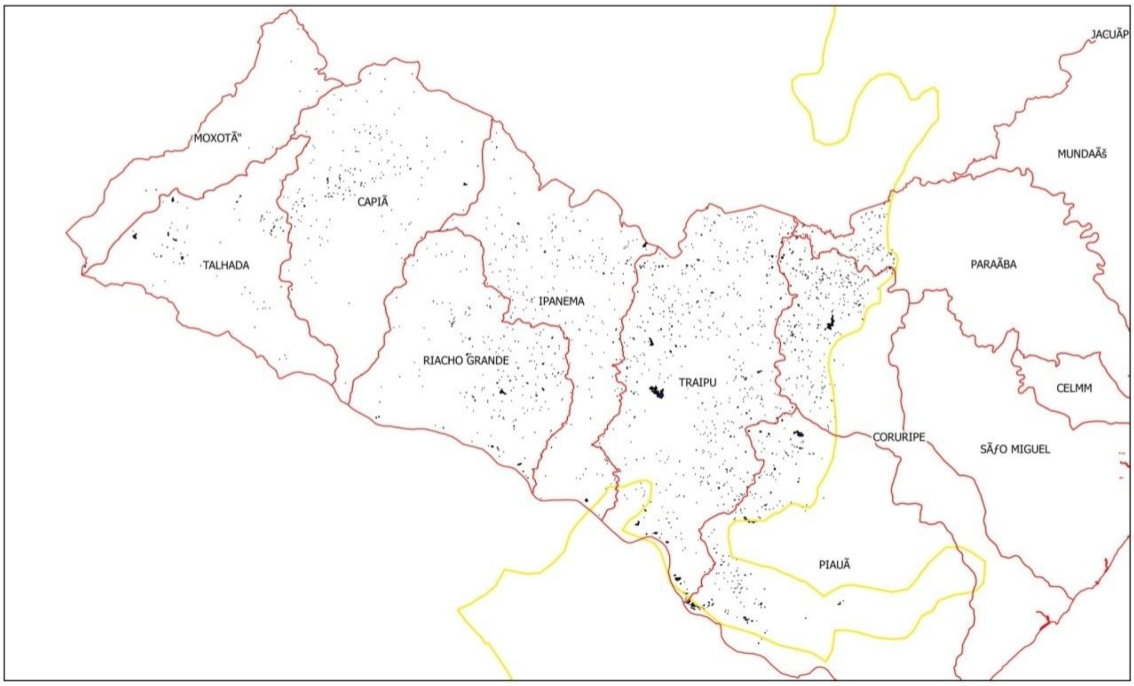
For 1987, the mapping identified 2,003 ponds/weirs (Figure 4), while for 2017, 3,133 ponds/weirs (Figure 5) were detected. At first, there was, therefore, a positive balance in the number of bodies of water between one year and the other, representing a 56.41% increase, or 1,130 "new" bodies of water. However, after processing and analyzing the resulting maps, the existence of three distinct groups of polygons defined in digital processing as surface bodies of water was observed between 1987 and 2017:

1) Corresponding: 660 polygons, 489 smaller than 1 ha – characterized by their existence in both 1987 and 2017;

2) New: 2,472 polygons, 2325 smaller than 1 ha – existed in 2017, but were not identified in 1987;

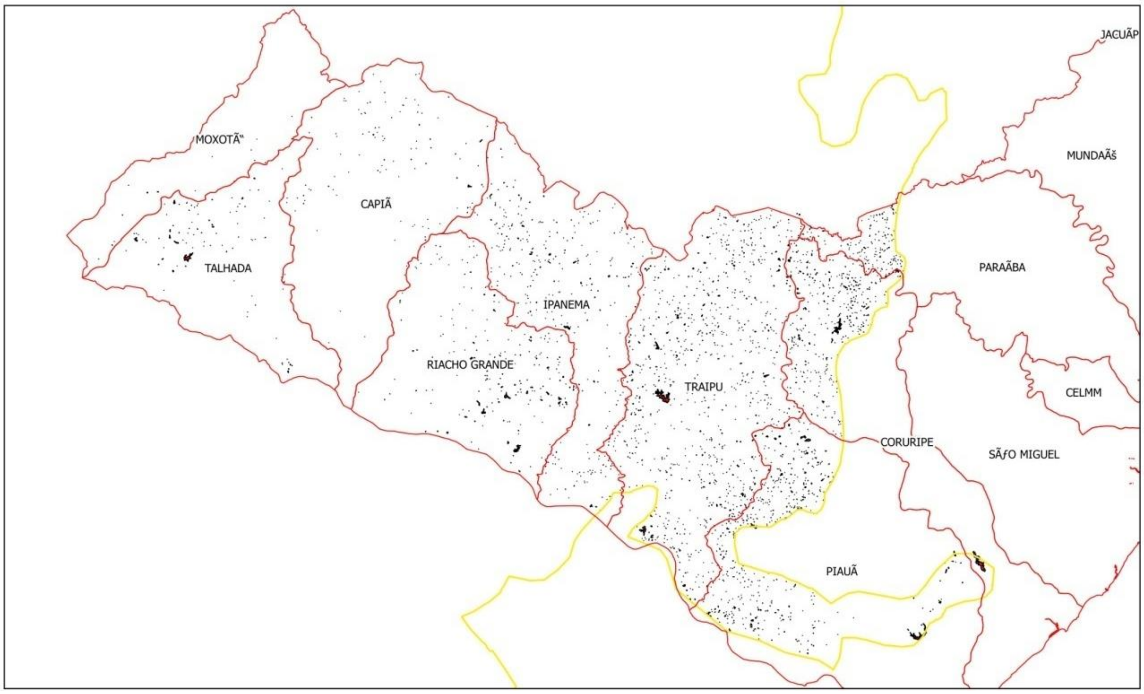
3) Disappeared: 1,349 polygons, 1,288 smaller than 1 ha – existed in 1987, but were not identified in 2017.

Figure 4 - Map of surface bodies of water in 1987 with 2,003 ponds/weirs (black polygons) in the *caatinga* biome area (yellow line) and the Hydrographic Regions (red line) in Alagoas.



Source - Authors (2019).

Figure 5 - Map of surface bodies of water in 2018 with 3,133 ponds/weirs (black polygons) in the *caatinga* biome area (yellow line) and the Hydrographic Regions (red line) in Alagoas.



Source - Authors (2019).

Most of these bodies of water are formed by small weirs with less than 1 ha – precisely the system of capture, storage, and supply that permeates the *sertão* in small and medium-sized rural properties, thus the group of ponds/weirs that "disappeared" certainly arouses greater research interest. The water system in the Brazilian semi-arid region is one of the objects of public policies created since the 40s of the 20th century in the northeastern semi-arid region, mostly executed with funds of the Federal Government through the *Companhia de Desenvolvimento dos Vales do São Francisco e Parnaíba* (Codevasf).

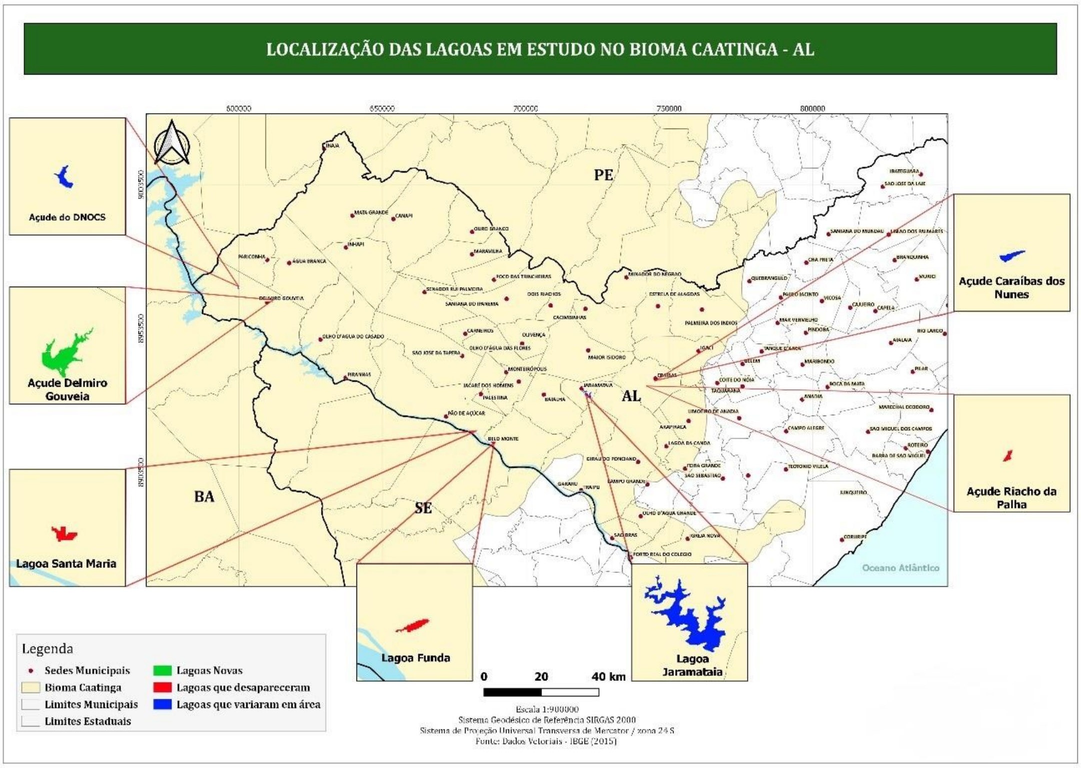
The large rural properties in this region have their own funds for the construction of large weirs or benefit from public funds to finance the project, as was the case of the DNOCS Weir in Delmiro Gouveia and the Jaramataia Weir in the city of the same name – both objects of field research.

Selection of candidates for on-site visits

To proceed with the on-site visits, which took place on five calendar days in July 2019, some mapped bodies of water were selected. The criteria used to choose the ponds were defined by the heterogeneity of the situation found, from the presence of at least one representative of each group (Corresponding, New, and Disappeared), greater variation (positive or negative) between the dates, and which could have some peculiar situation, and its territorial expression (*ex ante*, the largest reflecting pools should have socially expanded use, as it would be more relevant in the context of the research "*Climap – Mudanças Climáticas no Bioma Caatinga: Sensoriamento Remoto, Meio Ambiente e Políticas Públicas"* (Climap – Climate Change in the *Caatinga* Biome: Remote Sensing, Environment, and Public Policies), in which this study is inserted, to investigate them).

Based on this analysis, seven bodies of water were selected in five cities in Alagoas for field validation that met the adopted criteria: Delmiro Gouveia (*Açude do DNOCS* and *Açude da Pedra Velha*, also known as *Açude Delmiro Gouveia*), Pão de Açúcar (*Lagoa Santa Maria*), Belo Monte (*Lagoa Funda*), Jaramataia (*Açude de Jaramataia*), and Craíbas (*Açude Riacho da Palha* and *Açude Caraíbas dos Nunes*). The location of these ponds and weirs can be seen in Figure 6.

Figure 6 - Location map of the weirs and ponds selected for field research.



Source - Authors (2020)

Table 1 shows the variations in the reflecting pool area of ponds and weirs, both in hectares and in percentage values. This selection was important to assist in the programming of the field validation of the adopted methodology, since it is impossible to visit all mapped bodies of water.

Table 1 - Areas (ha) of ponds and weirs selected for field research.

Toponymy	City	Area 1987 (ha)	Area 2017 (ha)	Change (%)	Status
Açude do DNOCS	Delmiro Gouveia	33.5	20.6	-38.6%	Corresponding
Açude da Pedra Velha	Delmiro Gouveia	-	111.6	-	New
Lagoa Santa Maria	Pão-de-Açúcar	7.83	-	-	Disappeared
Lagoa Funda	Belo Monte	10.66	-	-	Disappeared
Açude Jaramataia	Jaramataia	244.2	296.8	17.7%	Corresponding
Açude Caraíbas dos Nunes	Craíbas	11.3	17.8	36.2%	Corresponding
Açude Riacho da Palha	Craíbas	8.2	-	-	Disappeared

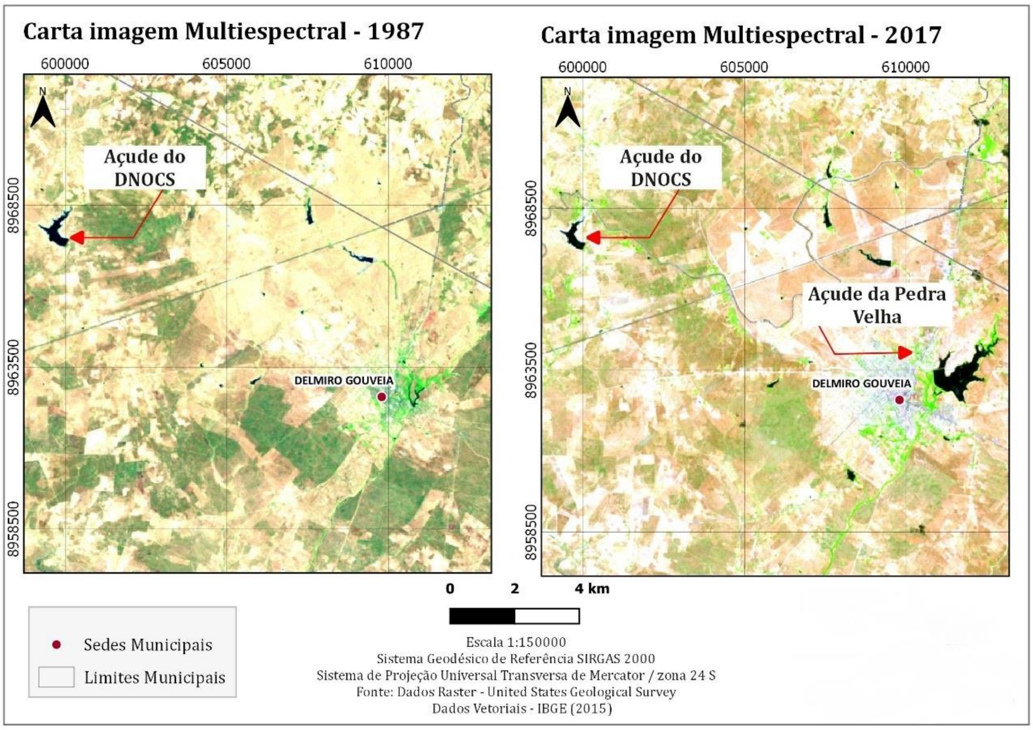
Source - Authors (2020), based on LandSAT 5/TM and 8/OLI image processing.

Field Validation

The first city to be surveyed was Delmiro Gouveia, with two weirs to be researched. Starting by the *Açude do DNOCS* (Figure 7), a body of water from the "corresponding" group and with reduction of 12.72 ha (or 38.6%) between 1987 and 2017. The field research found that it was constructed in the '40s (Figures 8 and 9) by the DNOCS.

According to reports by old residents, the weir has been losing water in the last 20 years. It actually practically never met the population's expectations, since the dammed water always had high salinity, which made its use unfeasible both for irrigation and fishing or human consumption. It is deduced that its construction certainly met political interests at the time and that, due to the non-consumption of its water resource since its creation, there is consistent evidence that its reduction between 1987 and 2017 by 38.6% (12.9 ha) was due to climate change.

Figure 7 - Details of the image maps of Delmiro Gouveia from 1987 (left) and 2017 (right) with the location of the *Açude do DNOCS* and the *Açude da Pedra Velha*, both in Delmiro Gouveia.



Source - Authors (2019).

Figure 8 - *Açude do DNOCS* (1946) in Delmiro Gouveia.


Source - Authors (2019).

Figure 9 - Ruins of the inauguration monument of the *Açude do DNOCS* (1946) in Delmiro Gouveia.

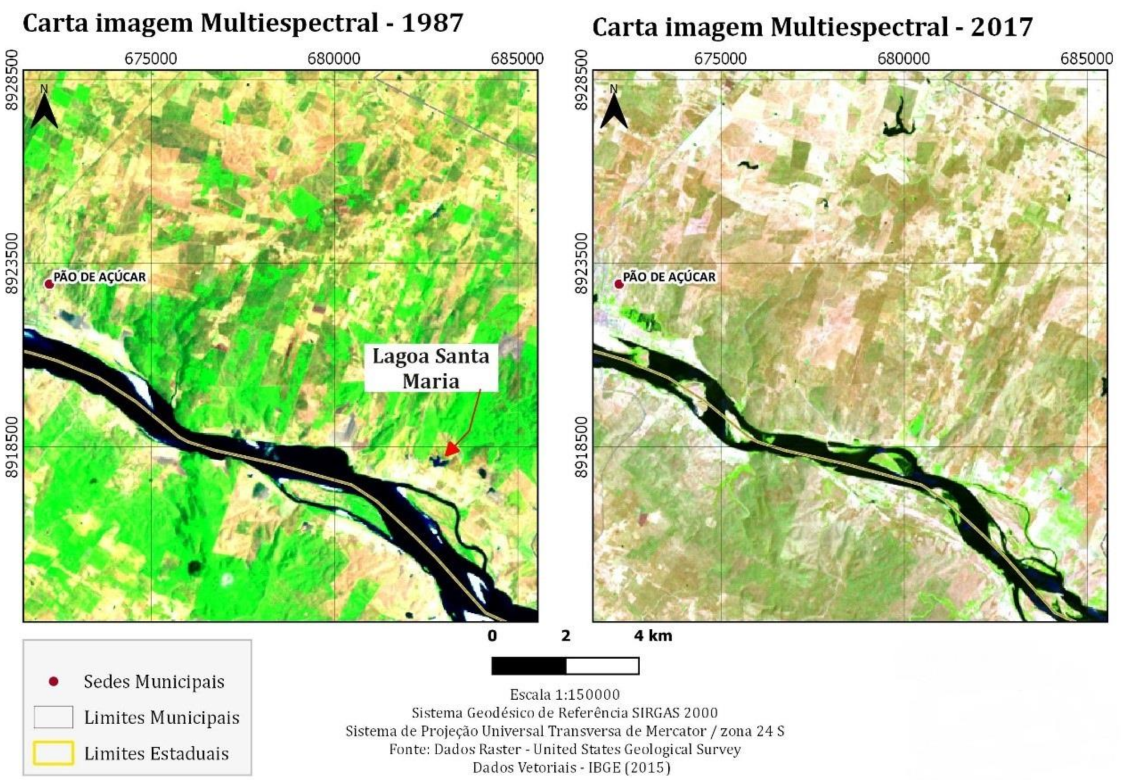
Source - Authors (2019).

The second weir investigated was in the city of Delmiro Gouveia itself: the Pedra Velha, from the group of "new" bodies of water, presenting in 2017 a 111.6 ha reflecting pool. It is the largest body of water in the *sertão* of Alagoas, built in the '90s and located on a large private property. The weir is not included in the 1987 image-map since it had not yet been built, but it appears with great territorial expression in the 2017 image-map. According to the interviews conducted at the site and with the Municipal Secretary of Environment, there is "no use of this weir", not even by the owner.

However, differently from what was mentioned in the interview with the Municipal Secretary of Environment of Delmiro Gouveia at the time, in a region marked by water scarcity and low levels of human development, having a reservoir of such magnitude represents an enormous political power to its owner. In fact, this is a characteristic of the civilizing process that goes back to the beginnings of humanity, because dominating access to water has an important meaning in the collective unconscious, associated with the territoriality of the power alliances of each society, in time and space. And in Delmiro Gouveia, in the high *sertão* of Alagoas, this is no different.

The second city to be researched was Pão de Açúcar, in the surroundings of *Lagoa Santa Maria*, in the northeast portion of the city, close to the São Francisco River (figure 10). The pond is in the group of those who "disappeared", although the research found a remnant of this body of water (figure 11), as the field was carried out in the rainy season (July 2019). With difficult access, the pond is on a well-structured private property, but it does not use the water intensively. There are reports of little artisanal fishing activity.

Figure 10 - Details of the image maps of Pão de Açúcar from 1987 (left) and 2017 (right) with location of the *Lagoa Santa Maria*, showing its "disappearance" between one year and the other during the study period.



Source - Authors (2019).

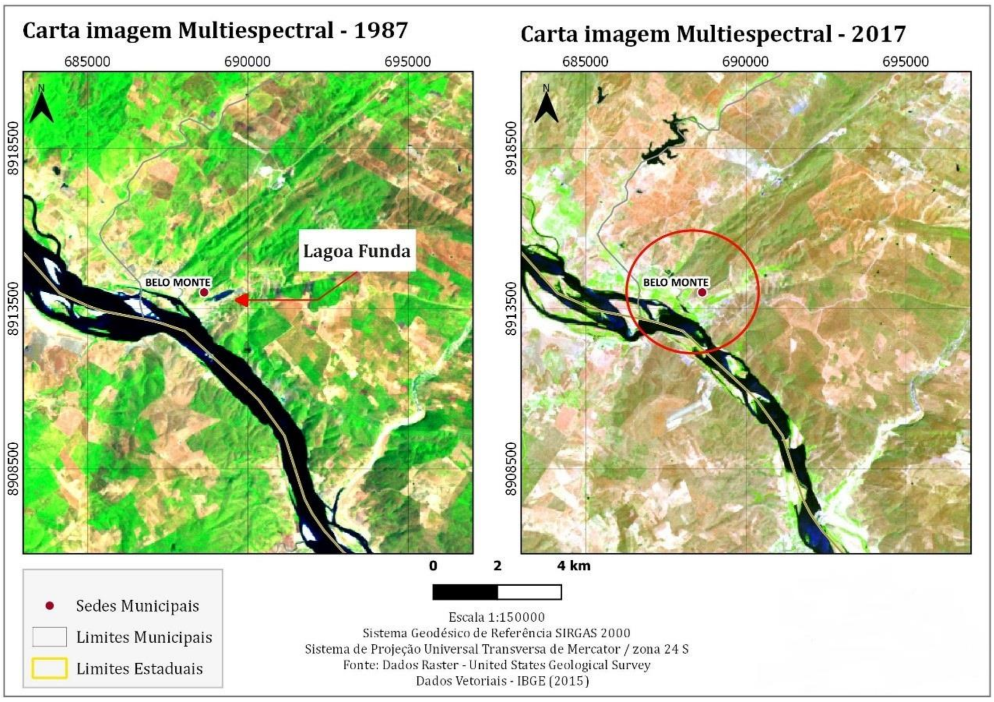
Figure 11 - Remaining of *Lagoa Santa Maria* in Pão de Açúcar.

Source - Authors (2019).

The third city researched was Belo Monte, next to *Lagoa Funda*, a body of water belonging to the group of those that "disappeared". This pond is part of the marginal pond system of the São Francisco River and, according to reports, when there was water in its bed, it lent its name to the former Vila Lagoa Funda. The toponymy changed even in the 19th century, thus predicting the end of the lagoon, around the 1990s. The details in the image map of Belo Monte show this dynamic (Figure 12). The field research revealed that the site does not offer any use to the local population, as it is a "dry" body of water.

The reasons for this exhaustion of the pond (Figure 13) seem to be related to the construction of the Xingó Hydro Power Plant, on the São Francisco River, between the States of Alagoas and Sergipe. In an interview with the Municipal Secretary of Environment of Belo Monte, the research found that, before the construction, with the greatest water volume of the São Francisco River and the most regular system of floods and droughts, a system of channels enabled the pond to receive water supply enough to maintain its reflecting pool, as evidenced in the 1987 image.

Figure 12 - Details of the image maps of Belo Monte from 1987 (left) and 2017 (right) with the location of *Lagoa Funda* already missing; at the site, what is seen in the image is the herbaceous cover of the old pond bed in light green color.



Source - Authors (2019).

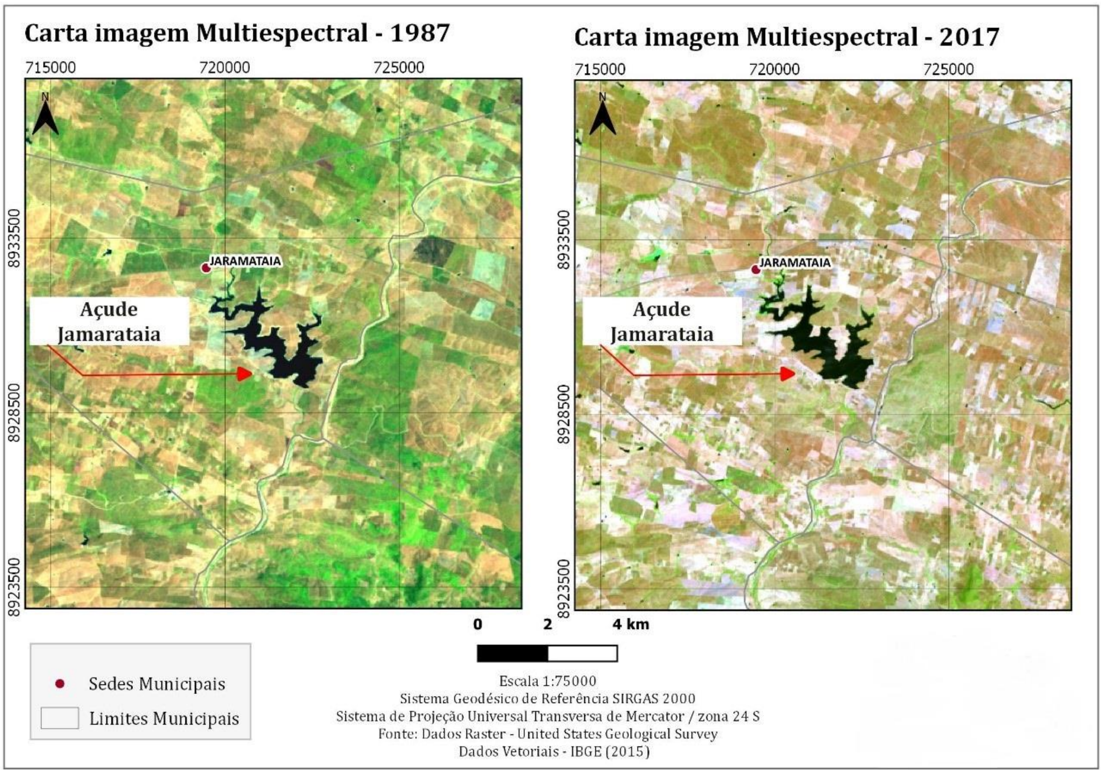
Figure 13 - Area where the old *Lagoa Funda* was located in Belo Monte with the area of the old pond channel now covered by grass.

Source - Authors (2019).

The fourth city to be surveyed was Jaramataia, with the weir that has the same name as the city (Figure 14). Built by Codevasf in the '90s, the weir has a tilapia (*Tilapia mossambica*) fingerling breeding unit of Codevasf that supplies about 36 other weirs in Alagoas.

These specific weirs are distributed throughout the territory of Alagoas and have fish farming in tank nets for consumption in the domestic market. Therefore, the weir has a regional importance and stands out in the economy for it supports the activity of tank net farming, in addition to supplying some cities of the region, characterized for being an ecotone between the semi-arid region and the *agreste*. However, the research identified water pollution problems due to the lack of adequate sanitary sewer, as the weir is within the urban nucleus.

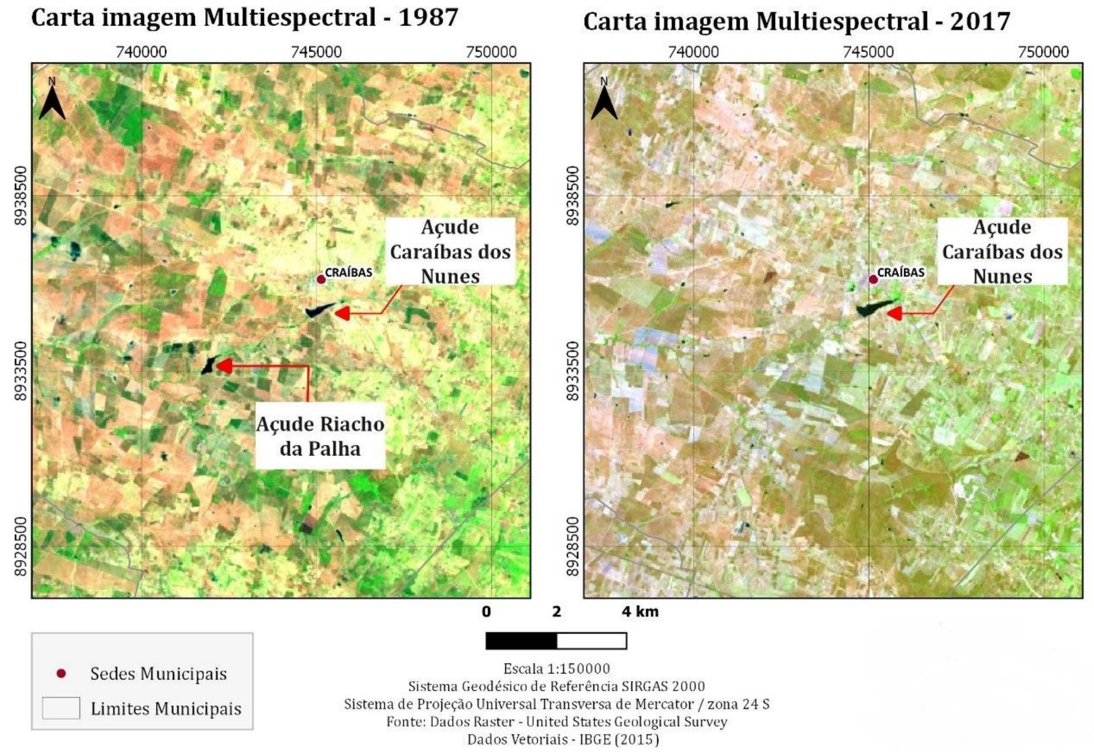
Figure 14 - Details of the image maps of Jaramataia from 1987 (left) and 2017 (right) with the location of the weir of the same name.



Source - Authors (2019).

The fifth and last city surveyed was Craíbas, with the surroundings of two weirs: *Riacho da Palha* (groups of those that "disappeared") and *Caraíbas dos Nunes* (group of the "corresponding" with an increase in reflecting pools of 6.5 ha). The satellite images show the dynamics of the bodies of water during a period of 30 years (from 1987 to 2017) with emphasis on the "disappearance" of the *Riacho da Palha* weir, probably due to the surface water volume or damming of the river of the same name. Interviewees reported a "simplification" and reduction of the region of the rivers and ponds, generally speaking, in the last 20 years (Figure 15).

Figure 15 - Details of the image maps of Craíbas from 1987 (left) and 2017 (right) with the location of the *Caraíbas dos Nunes* weir and the "disappearance" of the *Riacho da Palha* Weir.



Source - Authors (2019).

Former residents reported there was more water volume both in the weir of the city (*Caraíbas dos Nunes*) and in the weir of *Riacho da Palha*. The population uses the weir's waters for supply and recreation, but the research also identified pollution hotspots, caused both by the household waste accumulation deposited on the banks of the *Caraíbas dos Nunes* weir and the lack of sanitation that discharges raw waste into the weir (Figures 16 and 17).

Figure 16 - Raw sewage discharge into the *Caraíbas dos Nunes* Weir, in the city of Craíbas.

Source - Authors (2019).

Figure 17 - *Caraíba dos Nunes* Weir in Craíbas.

Source - Authors (2019).

CONCLUSIONS

The State of Alagoas owes its name to the abundance, economic potential, and scenic beauty of the surface bodies of water that from the earliest times aroused the greed of European conquerors and invaders. With three distinct geographic regions, the coastline, the *agreste*, and the semi-arid regions, the State's economy, culture, and history are linked to its peculiar hydrography. The semi-arid region, although it presents substantial rainfall deficits when compared to the coastline, it is provided with a weir and dam system, in addition to temporary rivers, which are distributed throughout the territory and are essential for the survival of the backlands populations, holders of low human development indexes and high social vulnerability.

In this scenario, evaluating the dynamics of surface inland bodies of water is of fundamental importance in order to subsidize public policies to mitigate global climate change with local effects. In this regard, the research showed, through modeling and processing of data extracted from temporal satellite images, the dynamics of these bodies of water in the last 30 years, between 1987 and 2017.

After defining a methodology suitable for the detection of bodies of water in multispectral images, the study revealed the existence of **three groups** related to ponds and weirs in the *caatinga* biome region in Alagoas.

The **first** of them, called "corresponding", referred to those ponds that existed in the images from 1987 and also from 2017. The **second** referenced the "new" ponds and the **third** represents those that have "disappeared", *i.e.,* refers to those ponds that disappeared from year to year.

Despite the positive balance during the observed period, because, while in 1987 2,003 ponds/weirs were identified, in 2017, 3,133 were identified, it is worrisome the fact that 1,349 bodies of water disappeared in a semi-arid region marked by scarcity, irregularity, inaccessibility, and poor water distribution. It should be noted that most of these small ponds and weirs that disappeared had an area inferior to 1 ha as a reflecting pool. Therefore, it is a matter of a possible collapse of the weir public policies in the *sertão* of Alagoas, bringing severe losses to the family and subsistence agriculture.

Another important aspect disclosed by the field research in seven ponds of five cities is related to different causes found for the reduction of some reflecting pools and the disappearance of others. Apparently, of the seven bodies of water, three have as probable causes the climate change (*Açude do DNOCS* in Delmiro Gouveia, *Lagoa Santa Maria* in Pão de Açúcar, and *Lagoa Funda* in Belo Monte), one has an exclusively political use *(Açude da Pedra Velha* in Delmiro Gouveia), and three are in urban nucleus threatened by the pollution of household waste or lack of sanitation in the cities (*Açude Riacho da Palha* and *Açude Caraíbas dos Nunes* in Craíbas, and Jaramataia Weir, in the city of the same name).

Left to their own fate, the ponds and weirs of the *caatinga* biome in Alagoas lack care for their maintenance, recovery, preservation, and depollution. It became evident in the research the need to rethink, reaffirm, reformulate the importance of public policies to mitigate climate change, whose consequences are already visible and immediate, as shown by the dynamics of the bodies of water over the last 30 years, marked by the "disappearance" of ponds and weirs and reduction of many others. Alagoas still does not have a legal framework to mitigate and fight against climate change, in a moment when legal multilateral agreements are being negotiated and put into practice around the world.

The emergence of new "natural" disasters, with the droughts and dry spells, as well as the techno-industrials disasters, such as the beginning of a great copper mining project in Craíbas, or even the ones in the health area, as COVID-19, demand speed and efficiency for the governmental actions. The overlapping of disasters brings multiplying effects to the high social vulnerability populations that inhabit this semi-arid region in Alagoas. The impacts are much greater and the consequences will be long-term. In this difficult scenario, the participatory public policies seem to indicate the best way to mitigate problems that affect everyone, but to a greater extent those with high social vulnerability. The climate change in the *caatinga* biome in Alagoas is one of those emergency situations in disasters that require attention, research, and agility from the whole of society.

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