

Analyses of Poções and Camalaú weirs after São Francisco's river transposition using morphological process on Sentinel 2 orbital images

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Abstract— Brazil suffers from the constant season drought, mainly in the northeast, directly affecting the water supply. Therefore, studies on the causes, effects and solutions have been developed and becoming of great importance for society. The São Francisco river transposition was designed to mitigate the drought supplying weirs along its course. Among them are Poções and Camalaú, located respectively in Monteiro and Camalaú in Paraíba state. In this sense, the paper aims to evaluate the temporal effect of drought on the Poções and Camalaú. Remote sensing images, obtained by Sentinel-2 satellite in four different dates, were used with digital image processing techniques to detect weir's area. Therefore, it was possible to verify the occurrence of a considerable increase of the area and, consequently, of the volume of water after during the first three years of the transposition. However, after a problem with the transposition, a drastic decrease in the flooded area of both weirs occurs. The paper presented an efficient use of digital image processing and Sentinel-2 images to perform a temporal evaluation of flood areas.

Keywords— Camalaú, mathematical morphology, Poções, Sentinel – 2A, temporal evaluation.

I. INTRODUCTION

Brazil, mainly in the northeast region, constantly suffers with the lack of rain. According to Azevedo et al (2018), its in the northeast region that more than 50% of the drought cases registered in Brazil occurs due to the semiarid climate periods of sparse rain.

In this sense, Santos et al (2018) affirms that a semiarid climate region has high rainfall variability, thus needs study about pluvial supply and storage alternatives in the region in a way that ensures better living conditions to the population. One of the alternative means is the Transposition of the São Francisco River.

The drought season is a natural phenomenon that is part of the climate variability of a determined region. Besides that, the occurrence of dry weather in a determined region

may cause undesirable impacts on the society, politics and environment. (Carvalho e Alcântara, 2018). It is known that about 57% of Brazil's northeast territory has been intensely utilized in the last decades, resulting in the severe degradation of natural resources (Marengo et al, 2012).

In this sense, after suffering with drought in Ceará, the Engineer Ferreira Filho determined the first possible solution when he suggested to Marco Antônio Macedo, manager of Crato's judicial district, to bring water to his state through São Francisco's river. This history originated the first transposition of São Francisco's river in 1847(FAPESP, 2016). A long the years, many names contributed with the project, however it has only began in 2007 and after twelve years, the constructions have not

finished yet and have already cost to the population approximately R\$ 9.6 billion, twice the initial budget.

The change of the water flow occurs in two stretches, east and north. In the east stretch, the smaller of the stretches, are localized the Poções and Camalaú weirs, at Monteiro and Camalaú cities respectively, both at Paraíba state. These two weirs supply 36 thousand inhabitants. Both weirs mentioned serve as passageway for water to reach Epitácio Pessoa weir, commonly known as Boqueirão. The Boqueirão weir is responsible for supplying approximately 1 million people in nineteen cities.

Nevertheless, in the first semester of 2017, the Boqueirão weir stored only 3.5% of its total capacity. Due to this emergency situation, São Francisco's waters arrived to Monteiro and Camalaú before the constructions ceased at these sites.

In this sense, it was verified the necessity to evaluate the behavior of the weirs of interest along the period in which São Francisco's River transposition began. Therefore, this work proposes a study and an evaluation, through remote sensing image and techniques and digital image processing, to verify the levels of water stored by the weirs of Monteiro and Camalaú before and after the water passage. Thus, this work presents the obtained results of the flooded area in both weirs of interest along the year in which the implementation of the transposition occurred, together with the analysis of the weirs' behavior in the studied period.

II. MATERIALS AND METHODS

Two test sites were selected for the realization of this study; the first test site is in the city of Monteiro and the second in the city of Camalaú. Both test sites have weirs included in the east transposition of São Francisco River, and on March 2017 the weirs started to receive São Francisco's water.

The analyses of the flooded area of Poções and Camalaú, were made utilizing collected data of Sentinel-2 satellite, these data were made available by the USGS (United States Geological Survey) in 2016, in the NIR wavelength with radiometric resolution of 12 bits per pixel and 10 m of spatial resolution.

Considering that São Francisco's waters arrived in the weirs of Poções and Camalaú, due the transposition made in March 2017, some images were selected on the dates of October 2016, November 2017, December 2018 and September 2019.

In the figure 1 there is an explanation of the test sites, referenced in the geodesic system WGS84; on the left side, the weirs of Poções and on the right side the weirs of Camalaú.

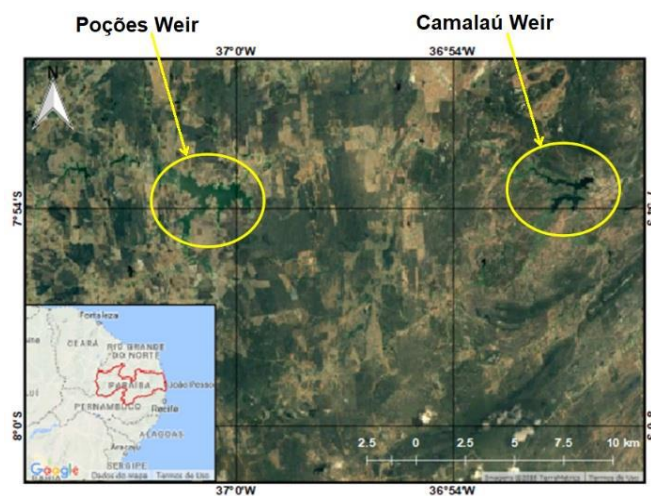


Fig. 1: Weirs location

The software Matlab was utilized to perform the processing of the acquired images, so that the extraction of the flooded areas of the studied weirs could have been made. Also, the software Cartomorph, developed in FCT-UNESP, was used to evaluate the results obtained on the extraction of the flooded areas.

III. EXTRACTION METHODOLOGY OF THE WATERBODIES

Aiming to facilitate the distinction of targets presented on images and consequently improve the results of the weirs extraction, the image processing was started with the histogram equalization.

In sequence an empirical binarization of these images was performed, aiming the weirs' segmentation. To do that, the digital number of a random pixel of the target was observed, this specific value is called threshold, and it was determined that the pixels with values above the threshold, would have their maximum digital number, that is, the pixels above the threshold would become white and the pixels below the threshold would become dark.

The next step was the transformation of the image in its opposite, that is do the image negative, in a way that the white pixels become dark pixels and vice versa. This step is necessary for the application of the next step, which is the noise removal.

To perform the noise removal, a function of area opening was applied. In this function a threshold is included that removes areas below the number of pixels specified. In

the end of the extraction the weirs areas were calculated, in the chosen dates, considering the spatial resolution of the chosen images.

IV. EXTRACTION ANALYSES METHODOLOGY

Aiming the quality extraction analyses, the metrics completeness and correctness were calculated utilizing the software Cartomorph, as described by Cardim, Silva and Dias (2014). The first step for this study was the manual feature extraction of the eight images, creating like that, the reference images for the statistical calculations, which are considered like ideal results of the extraction performed. Then, it determined a tolerance area around the target, which is going to be considered like a correct area during the comparisons between the reference images with the resulting image of the extraction process.

The comparison is made in two steps. First, the tolerance area is generated around the target in the reference image comparing it with the extracted image. In a second moment, an inverse comparison is made, that is, the reference image is compared with the extracted image increased of the tolerance image. The comparisons described are exemplified, respectively, by figures 2a and 2b.

The tolerance is also generated around the target in the automatically processed image, then, the processed image is compared to the reference image. These are exemplified in figure 2, where 2a represents the total number of reference image points that coincide with the extracted feature and 2b shows the points of the extracted image that coincides with the reference image.

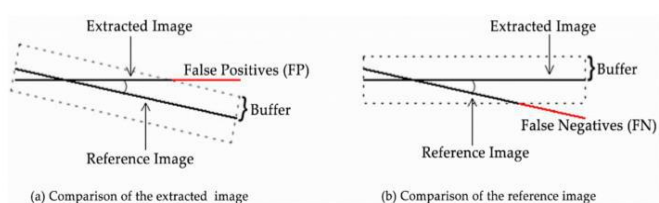


Fig. 2: Exemplification of completeness and correctness metrics

The metric completeness shows in percentage, how many pixels of the reference image were extracted correctly by the extraction method. To calculate this metric the equation 1 was used

$$\text{completeness} = \frac{\text{matched pixels of reference image comparison}}{\text{total of pixels of the reference image}}, \quad (1)$$

$$\text{correctness} = \frac{\text{matched pixels of extracted image comparison}}{\text{total number of pixels of the extracted image}}, \quad (2)$$

The metric correctness shows the percentage of pixels extracted from the image that coincide with the reference image. The calculation of this metric is given by the equation 2.

V. RESULTS AND DISCUSSION

i. Results of the waterbodies extraction

Considering that the raw images have 12 bits of radiometric resolution, it was necessary apply a contrast readjustment on the images to improve visualization and subsequent application of thresholds on them, as shown in figure 3. In addition, the extracted images used for detection of the weir's flooded area are presented in figure 4.

After performing all procedures described in methodology, it were obtained the results shown in figure 4.

Starting from the extraction results, the calculation of the flooded area was made by multiplying the amount of target pixels by the spatial resolution of Sentinel-2 in m².

Tables 1 and 2 show the comparison between the weirs' areas on the studied dates. The total area of the weirs was unknown; therefore, the date with the highest value of the extracted area was adopted as 100%. Therefore, the percentage of flooded area on the other dates, for both weirs, was calculated proportionally to the area adopted as 100%.

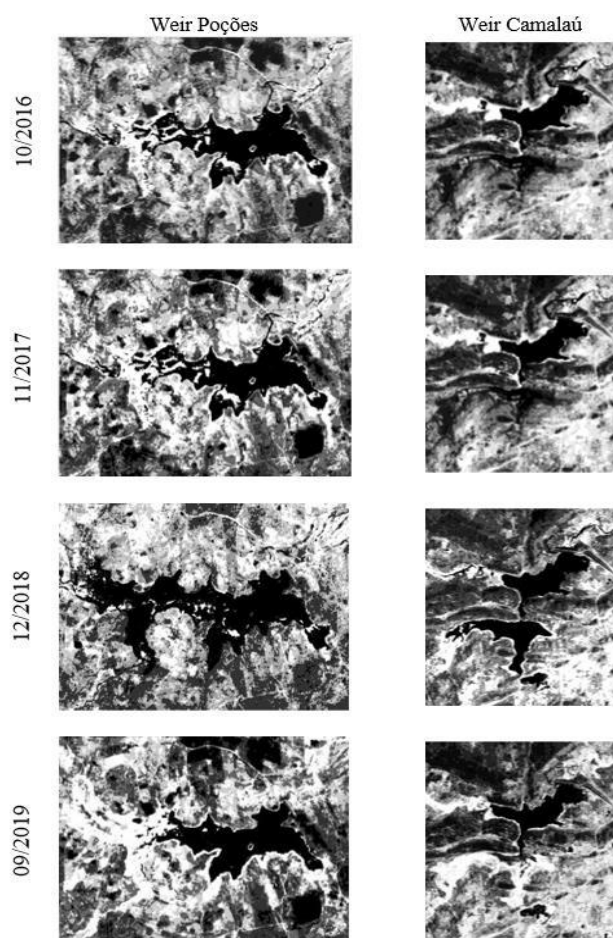


Fig. 3: Images of the Poçoões and Camalaú weirs on the four dates evaluated before the detection of the water bodies

Table.2: Calculated area of weir Camalaú

Date	Area (m ²)	Percentage
October 2016	783500	50,90
November 2017	828100	53,79
December 2018	1539400	100
September 2019	801800	52,09

Table.1: Calculated area of weir Poçoões

Date	Area (m ²)	Percentage
October 2016	395700	65,14
November 2017	387700	64,84
December 2018	607500	100
September 2019	296400	48,79

After applying the weir's extraction methodology, it was examined that in the course of a year, from October 2016 to November 2017, even with the arrival of River São Francisco's waters, it doesn't happen a significant improvement in the flooded area of the two weirs. This

happened due the transposition's canal rupture in the previous stretch of the studied area, where it was necessary to diminish the water flow to fix the rupture.

From November 2017 to October 2018, the Poçoões and Camalaú Weirs stopped receiving water due the resume of the recovery construction, this was necessary so that the weirs could storage the rainwaters safely. However, in November 2018, an inspection made by the Public Federal Ministry and the Public Ministry of Paraíba informed that the construction that receives water from Poçoões was able to receive water of the São Francisco River's transposition, thus the volume of Poçoões and Camalaú weirs increased considerably resulting in leakage of water from Poçoões to Camalaú. This fact can be observed through the extraction of water bodies in December 2018, where it presented the biggest calculated area in four years since the weirs were analysed.

Already with respect to the period from December 2018 to October 2019, the flooded area has halved on both weirs. This incident happened due to the low water flow to the Poçoões weir and the shutdown of the lifting station EBV6, which pumps the water from Poçoões to Camalaú.

ii. Results of extraction analyses

Using the software Cartomorph, with a pixel tolerance, a statistical analysis of the results obtained with the automatic weirs extraction was performed. The table 3 shows the calculated metrics.

Table.3: Statistical analysis of extraction results

Date	Weir	Completeness (%)	Correctness (%)
October 2016	Poçoões	99,2196	98,9967
	Camalaú	99,9998	97,0380
November 2017	Poçoões	99,9989	92,5363
	Camalaú	96,2914	99,1848
December 2018	Poçoões	99,8154	92,95330
	Camalaú	99,4083	98,86826
September 2019	Poçoões	99,9056	98,19109
	Camalaú	98,2565	99,09245

All statistical values obtained were superior to 90%, indicating excellent results for the targets extractions using mathematical morphology and thus validating analysis results of the flooded areas by the weirs in study.

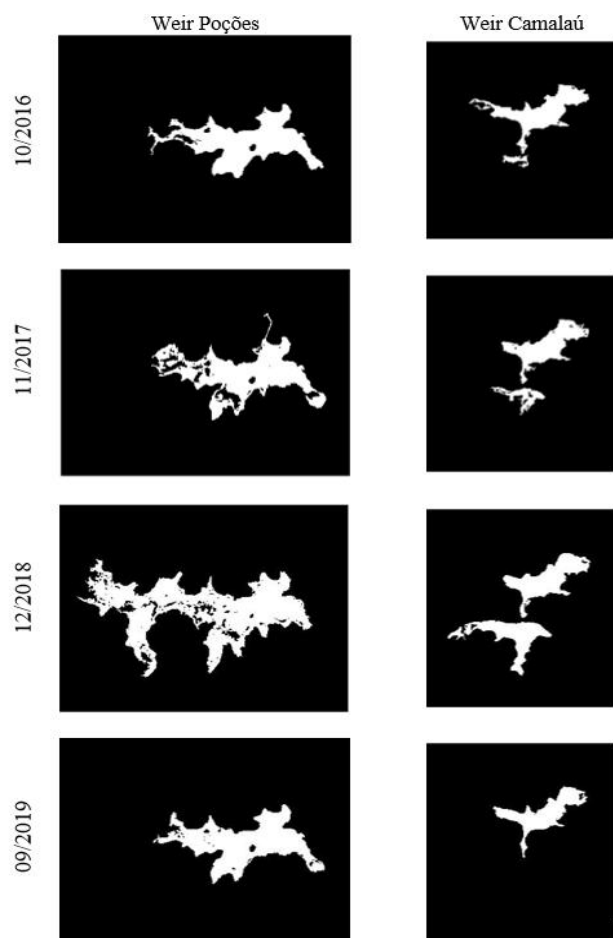


Fig. 4: Images of the Poções and Camalaú weirs on the four dates evaluated after the detection of the water bodies.

VI. CONCLUSIONS

The arriving of São Francisco River to Cariri region, where the weirs are located, happened later than expected and inadequately. Initially the construction would end in 2010, only three years after the beginning of the construction. Although, now a days, in 2019, the project has not been finished yet. Due to the second biggest drought in Boqueirão Weir's history, successor of the studied weirs, and considering the emergency in fueling the nineteen cities that depend of Boqueirão Weir, the water spill in the Poções and Camalaú Weirs was anticipated, that is, the spill occurred before the constructions' ending.

After almost three years of the inauguration, River São Francisco's transposition presents too many canals with seriously structural problems like fissures, sedimentation, vegetation that prejudice the water flow and the improper use of the water with irrigation above the permitted area.

Therefore, it is perceived that the non-supplying of the weirs does not happen only because of constructive factors, but also due an inappropriate use of the water by the

people. It is noticeable that after years of planning and execution of the transposition the fundamental thing has not been constructed yet, that is, the social and environmental conscience has not been constructed yet by the state and the population.

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