Revista Brasileira de Ciências Ambientais
Brazilian Journal of Environmental Sciences

Delimitation of water areas using remote sensing in Brazil's semiarid region

Delimitação da área de reservatório de água utilizando técnicas de sensoriamento remoto no semiárido do Brasil

Debora Natália Oliveira de Almeida[1], *Diêgo Cezar dos Santos Araújo*[1], *Débora Rodrigues Soares*[1], *Francisco Marcelo de Alencar Maia*[1], *Suzana Maria Gico Lima Montenegro*[1], *Sylvana Melo dos Santos*[1], *Leidjane Maria Maciel de Oliveira*[1]

ABSTRACT

Remote sensing techniques are of fundamental importance to investigate the changes occurred in the terrestrial mosaic over the years and contribute to the decision-making by increasing efficient environmental and water management. This article aimed to detect, demarcate and quantify the hydric area of Poço da Cruz reservoir, located in Ibimirim, Pernambuco, semiarid region of Brazil, with modeling based on Landsat 8/OLI satellite multispectral images from 2015 to 2020, and to relate it with data from the Climate Hazards Group InfraRed Precipitation with Station (CHIRPS) satellites average rainfall. For this purpose, the Modified Normalized Difference Water Index (MNDWI) was modeled, being produced georeferenced theme maps and extracted only the pixels represented by positive spectral values, which represent water targets. The open-access software Quantum Geographic Information System (QGIS, version 2.18.16) was used for all stages of digital image processing and connection with complementary databases on the theme maps elaboration. In the results, changes in the spatial distribution of Poço da Cruz were evidenced and analyzed using precipitation data from the CHIRPS product, allowing a better understanding of the rainfall behavior in the region and its influence. The MNDWI was lined with the CHIRPS product, in which the spatial correlation between the rainy event and the water area's delimitation is documented, especially in October 2017 (minimum values) and October 2020 (maximum values).

Keywords: geoprocessing; multispectral images; modified normalized difference water index.

RESUMO

As técnicas de sensoriamento remoto são de fundamental importância para investigar as alterações ocorridas no mosaico terrestre ao longo dos anos e contribuir para tomadas de decisão cada vez mais eficientes em gestão ambiental e hídrica. Os objetivos deste artigo foram detectar, delimitar e quantificar a área hídrica do reservatório Poço da Cruz, localizado em Ibimirim, Pernambuco, Semiárido do Brasil, com modelagem baseada em imagens multiespectrais do satélite Landsat 8/OLI datadas de 2015 a 2020, bem como relacioná-la com dados de precipitação pluvial média do produto CHIRPS. Para tanto, foi modelado o Índice de Água por Diferença Normalizada Modificado (MNDWI), com o qual se geraram os mapas temáticos georreferenciados e extraíram-se apenas os *pixels* representados por valores espectrais positivos, que representam alvos hídricos. Utilizou-se o *software* de livre acesso QGIS 2.18.16 para todas as etapas de processamento digital de imagens e conexão com bancos de dados complementares para a elaboração dos mapas temáticos. Nos resultados foram evidenciadas as mudanças na distribuição espacial do Poço da Cruz, analisadas com a utilização de dados de precipitação com base no produto CHIRPS, permitindo melhor compreensão do comportamento da pluviometria na região e sua influência. O MNDWI foi condizente com o produto de precipitação do CHIRPS, e ficou evidente a variação área hídrica do reservatório com relação à ocorrência de eventos chuvosos, especialmente em outubro/2017 (mínimos valores) e outubro/2020 (máximos valores).

Palavras-chave: geoprocessamento; imagens multiespectrais; índice de água por diferença normalizada modificado.

[1]Universidade Federal de Pernambuco – Recife (PE), Brazil.

Correspondence address: Debora Natália Oliveira de Almeida – Departamento de Engenharia Civil e Ambiental, Centro de Tecnologia e Geociências, Universidade Federal de Pernambuco – Avenida da Arquitetura, s/n – Cidade Universitária – CEP: 50740-550 – Recife (PE), Brazil. E-mail: debora.noalmeida@ufpe.br

Conflicts of interest: the authors declare no conflicts of interest.

Funding: Conselho Nacional de Desenvolvimento Científico e Tecnológico, Coordenação de Aperfeiçoamento de Pessoal de Nível Superior, Fundação de Amparo à Ciência e Tecnologia de Pernambuco.

Received on: 12/14/2022. Accepted on: 02/03/2023

https://doi.org/10.5327/Z2176-94781524

Introduction

The superficial water is essential to human supply and ecological conservation, becoming a key component of the hydrological cycle and directly conditioning the sustainable development of human society and ecosystem. Both climate changes and human activities affect the superficial water availability in a specific area and epoch (Lu et al., 2019).

One of the most viable ways to quantify water bodies' seasonal variation is using orbital images obtained by remote sensing. This technique has been advancing considerably in the latest years, enabling the acquisition of more accurate and detailed information, especially to identify and classify targets on earth surface that may facilitate several studies, such as land use mapping, dynamics of vegetation, and superficial waters. (Fernandes et al., 2012; Penachio et al., 2020).

For that matter, several studies performed through remote sensing data have confirmed the effectiveness and feasibility of orbitals images used in the geospatialization and evaluation of changes in terrestrial surface. One of them was evidenced by the Guglielmeli et al. (2018) that, through Landsat satellite images, elaborated maps of use and cover land referring to the municipal ambiental protection area of Uberaba River and evaluated the impact the conservation unit brought to the region in the years 2000, 2010 and 2016. The results of this research pointed out that the establishment of the conservation unit contributed to regulating the land's uses and cover.

It is also evident the research carried out by Ornellas et al. (2022) that conducted the temporal mapping between 1986 and 2020 with satellite images of the TM Landsat 5 and OLI Landsat 8. The objective of this work was to investigate the dynamic of marine area's land use — protected by Iguape Bay through spectral indexes — in which the behave and contribution of the mangrove areas in that region was analyzed.

In the hydric context, researches are evidenced in the evaluation of changes in superficial waters dynamics, and these analyses are applied on regional or global scale (El-Asmar and Hereher, 2011; Song et al., 2014; Verpoorter et al., 2014; Feng et al., 2015; Tulbure et al., 2016; Wan et al., 2016; Klein et al., 2017).

Among the diverse techniques, there is the multiband method, which combines different reflective bands to enable the detection of superficial waters (Du et al., 2012; Zhang et al., 2017; 2018). For instance, the Modified Normalized Difference Water Index (MNDWI) can be cited, which detects superficial hydric bodies while suppressing build-up land errors, as well as soil and vegetation (Xu, 2006). In this way, performing studies with spectral indexes application on hydric bodies detection, Almeida et al. (2021) highlighted that the referred index, processed with satellite data, has been widely used to evaluate changes in soil cover and use, mainly focusing on the detection of hydric bodies in vast areas.

In regard to this detection of hydric bodies, generally, before comparisons are made to detect changes in superficial waters, it is necessary to conduct an extraction of the water's individual aspects through the use of multi-date satellites, according to Alesheikh et al. (2007) and Rokni et al. (2014).

Considering also the hydric changes on large scale, there are global level studies, such as the one developed by Pekel et al. (2016), which was capable to quantify the changes in global superficial waters over 32 years, between 1984 and 2015, using Landsat images with 30 meters resolution (Lu et al., 2019).

Taravat et al. (2016) who searched the modifications occurred between the years 2000 and 2013 in Urmia, Sevan and Van lakes, sited respectively on Iran, Armenia and Turkey, recognized the efficiency of water extraction through orbital images applying water indexes, supporting the monitoring of these hydric bodies that are relevant to the surrounding living population.

Lu et al. (2019) stated that multiple surveys of regional cases were developed in China, and, consequently, some data set about superficial waters was produced in pilot areas (Du et al., 2012; Lai et al., 2013; Luo et al., 2017). This fact sets precedents to conduct similar studies on the Brazilian territory.

In Brazil, the National Institute for Space Research (INPE, 2022) has performed projects that contemplate a data set on the superficial area variations occurring in water reservoirs in the northeast region of the country as a consequence of the drought's frequent incidences suffered over the years.

In accordance with the superficial water monitoring, precipitation is one of the factors that influences the variations occurring in these spaces, mainly when focused on semiarid regions. Resources like orbital sensors products, interpolator algorithms and atmospheric models are increasingly necessary to represent precipitation in areas where it is not possible to observe or is deficient in rainy stations, becoming options for climatic studies on tropical and subtropical regions of the Brazilian territory (Bayissa et al., 2017). Diverse researchers utilized data sets raised by weather stations and satellite products to analyze the accuracy of precipitation estimates (Erazo et al., 2018; Corrêa, 2020). Among the precipitation estimate products most used at global level, including Brazil, stands out the Climate Hazards Group InfraRed Precipitation with Station data (CHIRPS), which has a series of data of more than 40 years, with spatial high-resolution and low uncertainties on rain registrations (Guo et al., 2017; Bai et al., 2018; Costa et al., 2019).

It is important to note that the delimitation of hydric bodies using the MNDWI, as cited above on performed works, is not a new practice and is already widely consolidated around the world. However, the continuous monitoring of regions or strategic locales is essential to ensure the management of water resources, alert emissions and enhance the decision-making actions. In this way, the use of remote sensing data applied in semiarid regions for this type of study has a high potential to assist regional, state, or national management authorities, especially in the recent drought events in the Brazilian semiarid region (Souza et al., 2018; Araújo et al., 2021).

Considering the above, the aim of this article was to detect, delimit, and quantify the hydric area of Poço da Cruz water reservoir located in Ibimirim, Pernambuco (PE), semiarid of Brazil, with modeling based on Landsat 8/OLI satellite multispectral images and relate with the data of media pluvial precipitation of the product CHIRPS, from 2015 to 2020.

Methodology

The study area encompassing the municipality of Ibimirim (PE), Brazil (Figure 1) is in the central area of the hydrographic basin of Moxotó River. This basin has a total area of 9,752.71 km^2, that in large extension is found in the Pernambuco State, inserted on the Hydric Planning Unit UP8 and has its location between 07º 52' 21" and 09º 19' 03" south latitude, and between 36º 57' 49" and 38º 14' 41" west longitude (APAC, 2022).

The Engenheiro Francisco Sabóia public dam, commonly known as Poço da Cruz, is the biggest water reservoir in Pernambuco state and the first hydric spring for irrigation of the Moxotó Irrigated Perimeter. It is one of the reservoirs inserted in the São Francisco River Irrigation Project (National Water and Basic Sanitation Agency—ANA, 2022).

The Landsat 8/OLI satellite image, that contemplates the study area, was acquired through the orbital images catalog on the site of the United States Geological Survey (USGS), on orbit 215, 66 Point. The bands used to obtain the MNDWI were the green, near-infrared and shortwave infrared, which correspond, on an OLI sensor, to the bands 3 and 6. They were processed on the free access Quantum Geographic Information System (QGIS), version 2.18.19, with Universal Transverse Mercator (UTM) coordinate system projection and SIRGAS 2000 Geodesic Reference System. One of the parameters for choosing the images was the low cloud coverage considering that the presence of clouds can interfere with the results; taking into account that it is a matter of estimating data, depending on the conditions, it is not possible to adequately represent reality. In the images catalog, it was possible to select the dates referring to October, namely: 10/29/2015, 10/15/2016, 10/20/2017, 10/21/2018, 10/24/2019, and 10/26/2020, which is considered the driest period in the Brazilian semiarid.

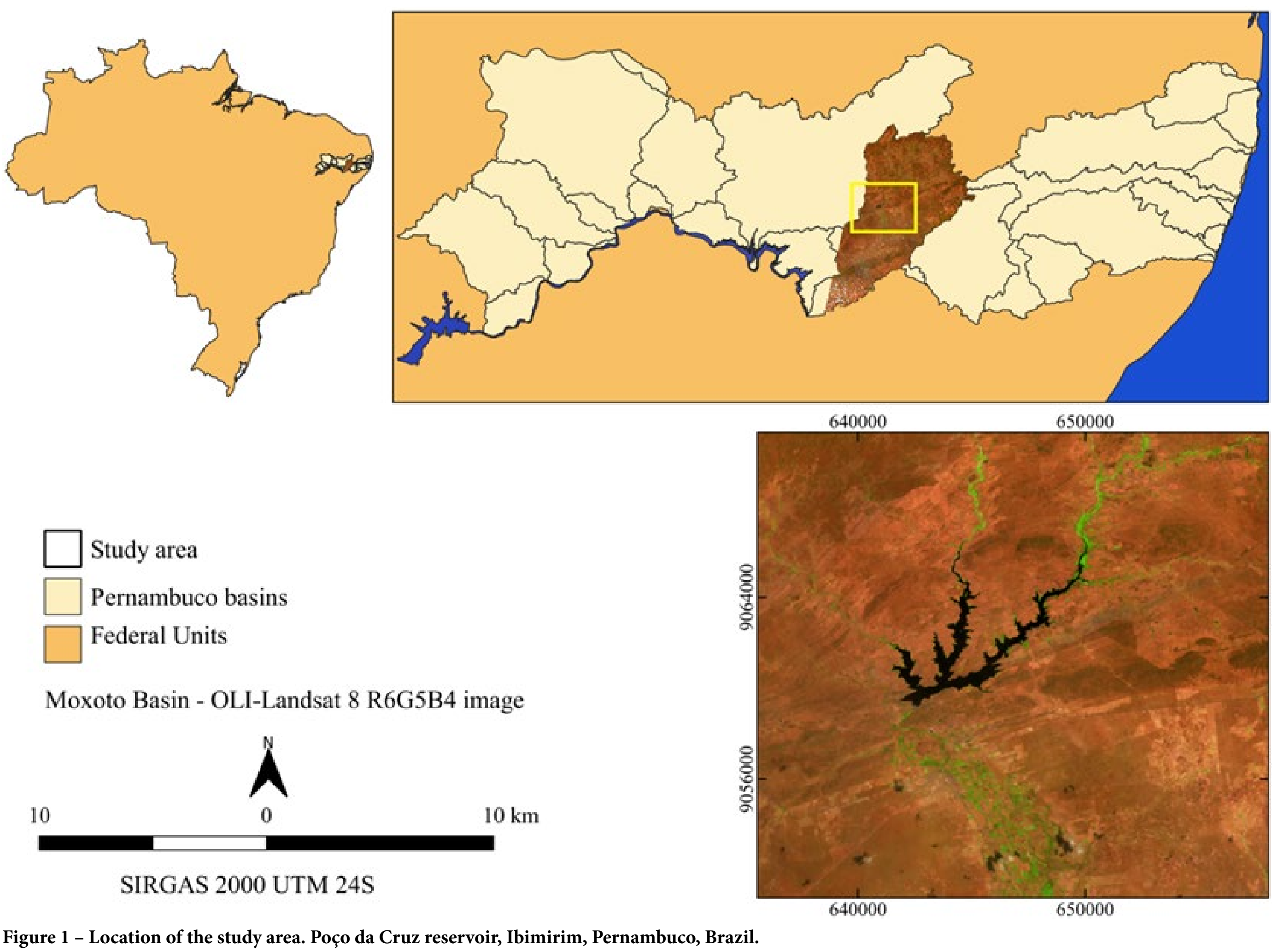


Figure 1 – Location of the study area. Poço da Cruz reservoir, Ibimirim, Pernambuco, Brazil.

To the georeferenced modeling of the MNDWI's charts, according to Silva et al. (2016), the first procedure was the conversion of values in gray level (ND) to spectral reflectance, inserting the radiometric coefficients available on metadata archives in the USGS (2022) images. Thus, the digital numbers of each pixel and band were converted into planetary reflectance stemming from additive and multiplying factors, reported in the image metadata file. However, it was necessary to correct the reflectance according to the solar zenith angle (Z) and the ratio square between the medium distance Earth-Sun, and the Earth-Sun distance on the date of the orbital image obtention (d_r), obtained based on the Earth-Sun distance (d_{TS}), available on the image metadata file, in astronomical unit, following the Equations 1 and 2.

$$\rho_{\lambda i} = \frac{(A_{\rho i} + M_{\rho i} . ND_i)}{cos\, cos\, Z . d_r} \quad (1)$$

$$d_r = \left(\frac{1}{d_{TS}}\right)^2 \quad (2)$$

being:
$\rho\lambda i$ (adimensional) = the planetary reflectance on top of atmosphere of each band i;
$A\rho_i$ = the resizing additive factor of each band (image's metadata);
$M\rho_i$ = the resizing multiplying factor of each band (image's metadata);
ND_i = the digital number corresponding to pixel intensity of each band;
Z = the solar zenithal angle obtained based on the Sun elevation angle-E (image's metadata), once Z = 90 – E.

The MNDWI was processed to maximize the reflectance in water using green wavelengths to minimize the low near-infrared (NIR) reflectance by the water characteristics, and to harness the high NIR reflectance by the soil and vegetation characteristics. As a result, the water characteristics had positive values and were therefore improved, while vegetation and soil generally had zero or negative values and were consequently suppressed. The MNDWI was then expressed in Equation 3 (Xu, 2006):

$$MNDWI = \frac{\rho Green - \rho SWIR1}{\rho Green + \rho SWIR1} \quad (3)$$

being:
$\rho Green$ = the reflectance of the green band;
$\rho SWIR1$ = the reflectance of the shortwave infrared band.

Thereby, the processing of MNDWI resulted in rasters whose values varied from 1 to -1, with the positive values representing pixels configured as hydric areas and the negative values representing pixels different from water. For the quantification of areas occupied by water bodies, the rasters with calculated values of MNDWI were transformed into a shapefile of dots.

The quantification of hydric total area was effectuated by multiplying the dots quantity and the pixel's area, being 900 m² of MNDWI, since the spatial resolution of the Landsat 8/OLI corresponds to 30 meters. The hydric total area occupied by the water reservoir was determined by the Equation 4, using the QGIS Raster Calculator:

$$At = \Sigma npixel . Apixel \quad (4)$$

being:
At = hydric total area; $\Sigma npixel$, the number of dots considered as hydric area;
$Apixel$, representing the pixel area (900 m² to Landsat 8/OLI).

The extraction technique of water spectral characteristics through the MNDWI was applied to model the spatial-temporal changes of the Poço da Cruz (PE) reservoir from 2015 to 2020, using Landsat 8/OLI. For this purpose, the selected index was shaped, analyzed, and classified into an independent form (using specific images thresholds) to extract the surface area of the reservoir in each year. Finally, the generated maps overlapped to produce the alteration map of the reservoir superficial water in the period from 2015 to 2020.

Additionally, monthly data were used, relating to October, the mean pluviometric precipitation of the CHIRPS product corresponding to the Moxotó River's hydrographic basin delimitation, where the Poço da Cruz reservoir is located. It is worth highlighting that the CHIRPS is not a satellite or orbital sensor, but a product of global precipitation that integrates multiple sources data, including surface data (rain gauges) and the Tropical Rainfall Measuring Mission (TRMM) satellite. In this work, we used rain data related to the product with a spatial resolution of 5 km and daily temporal resolution.

Results and Discussion

The results of the spatial precipitation distribution arising from CHIRPS product in the region, from 2015 to 2020, allowed observing the rain variability, in which the mean values to October reached the interval of 2 mm (represented by red shade) to 10 mm (represented by light blue shade) over the six researched years, as seen in Figure 2. To facilitate visualization, due to restrictions on the CHIRPS spatial resolution, the submitted values in the figure represent a media for all the image clipping and do not express the precipitation, necessarily, only over the reservoir.

In line with the CHIRPS data registries, in the state of Pernambuco, October is considered one of the driest months, but in October 2017, the precipitation was inferior to 25.00 mm in *the Litoral e Zona da Mata pernambucana*, inferior to 10 mm in the *Agreste*, and there were registries of low precipitation in the *Sertão*. The precipitation and cloud's absence resulted in temperature increase, and consequently, the evapotranspiration and dry areas increase throughout the state (ANA, 2022).

According to the descriptive statistics data, the lowest average value (3.65 mm) for the entire area occurred between 2017 and 2019 (CHIRPS), while the highest medium value (7.50 mm), in comparison to the studied years, was registered in 2020 (Table 1).

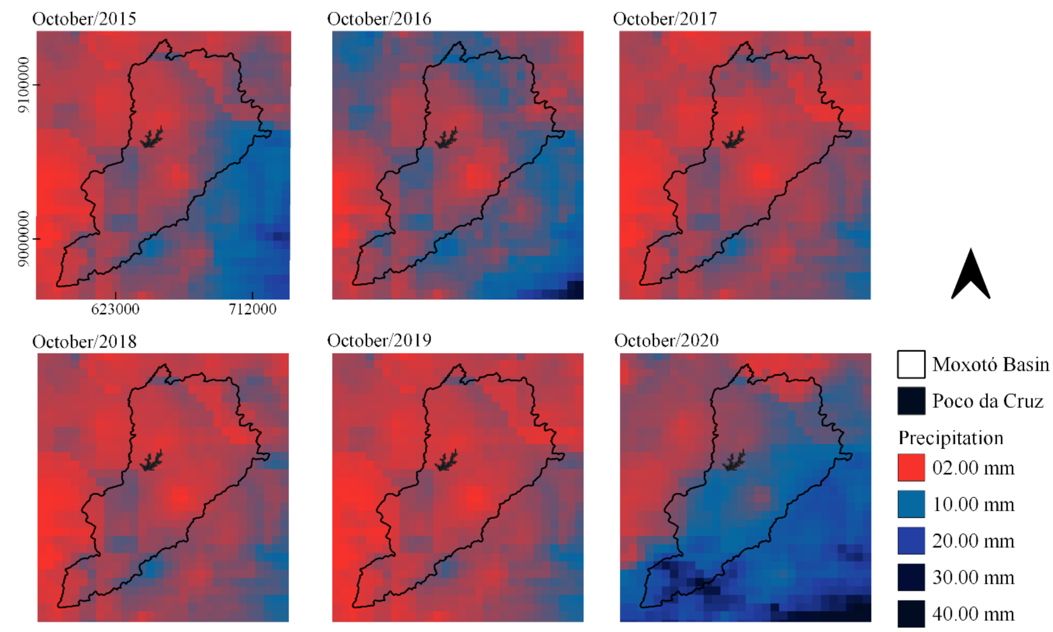


Figure 2 – CHIRPS data temporal series referring to hydrographic basin's delimitation of Moxotó River, Pernambuco, Brazil.

Table 1 – Precipitation's statistical values from the Climate Hazards Group InfraRed Precipitation with Station data product on the Moxotó River basin, Pernambuco.

Precipitation (mm)	Maximum	Medial	Minimum	Standard Deviation
October 2015	7.20	4.45	2.90	1.03
October 2016	8.15	5.10	3.50	1.15
October 2017	6.40	3.90	2.60	0.95
October 2018	6.55	3.95	2.65	0.95
October 2019	5.55	3.65	3.00	0.70
October 2020	10.20	7.50	5.00	1.50

Source: CHIRPS (2022).

Designed researches point out the evaluation of the CHIRPS accuracy to some globe's regions such as West Africa, Mozambique, Chile, Minas Gerais State (Brasil), Adige Basin (Italy), in which the applicability of product data in diverse climate conditions is assessed (Funk et al., 2015; Toté et al., 2015; Dembélé e Zwart, 2016; Duan et al., 2016; Nogueira et al., 2018). The CHIRPS has also been validated in the Brazilian Northeast and in semiarid conditions, presenting a good response in detecting precipitation (Paredes-Trejo et al., 2017).

In concern to the contribution in temporal-space evaluation applied in the reservoir Poço da Cruz, Ibimirim (PE), the MNDWI steaming was processed from the Landsat 8/OLI satellite system's images available on the period from 2015 to 2020, in the months of October, and without incidence of cloud's significative interference.

The variations that occurred, allowed us to identify the years in which the water's surface area was found steeper, as well as the years which evidenced a decrease. Thus, it was clearly outlined the variation in the reservoir's hydric area, a result corroborated by Rokni et al. (2014) in which it was assessed the Urmia Lake, in Iran, the 20th bigger lake and the 2nd biggest hypersaline lake (before September 2010) in the world. In the referred research, the authors processed water spectral indexes, among them the MNDWI, and the results indicated an intense tendency of decrease in Urmia Lake's surface area from 2000 to 2013, mainly between 2010 and 2013, when the lake lost approximately a third of its surface, compared to the year 2000. Although the studies have been developed in distinct locals, it is evident the potential of the MNDWI in detecting hydric areas variation in the outcome of extreme climatic events, such as the one that occurred in Pernambuco in the estimated period, with the impact that still remnant of the most severe drought on the last's decades, initiated in 2012 (Rossato et al., 2017). Similar situation occurs in Urmia Lake, which has suffered continuously with the impact of droughts and climate changes (Jeihouni et al., 2017).

In addition, the application of MNDWI is the most adequate to improve information on water and can extract the water bodies with better precision (Xu, 2006; Singh et al., 2015), allowing to visualize the droughts and floods (Figure 3) that, in this region, are conditioned mainly by the pluviometric precipitation variance.

The Figure 3 most remarkable shape is a delineation of the hydric body edges by MNDWI's modeling. This index allowed in a satisfactory way to split targets that represented water, showed by values next to 1, while target not considered as water evidenced pixels with negative values (MNDWI<0).

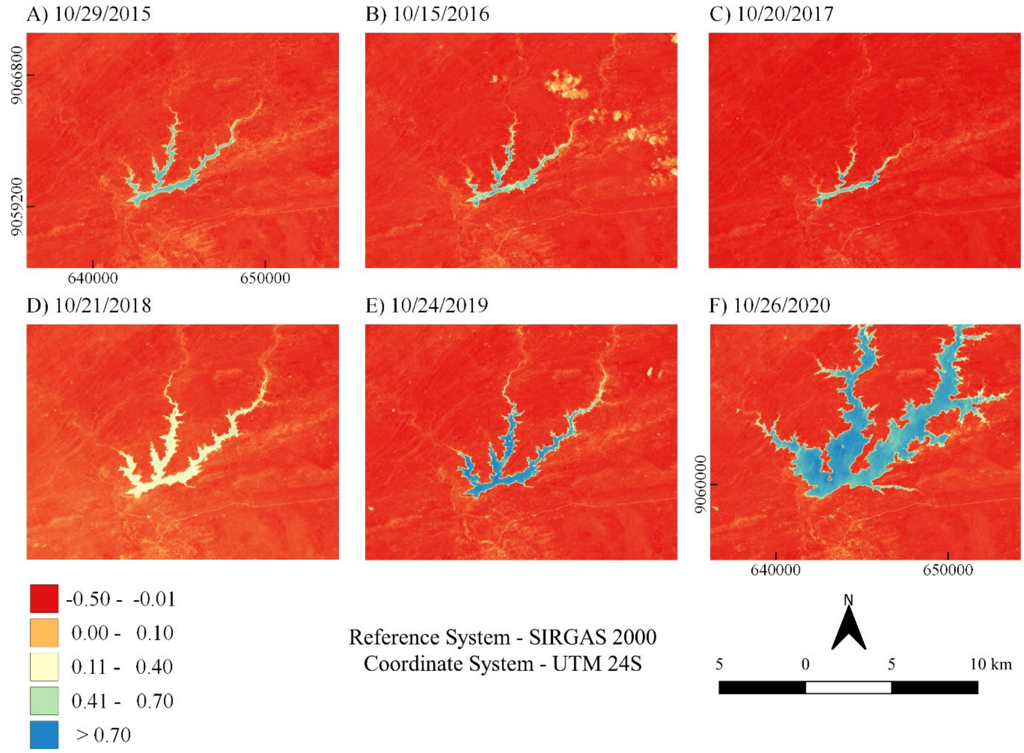


Figure 3 – Evaluation of Poço da Cruz reservoir through the MNDWI using Landsat 8 /OLI images.

This result coincides with Xu (2006), who also found positive values in areas with water presence and negative values in regions with absence of superficial liquid water (vegetation, soil, or construction).

In relation to Landsat satellite's spatial resolution, Cohen and Goward (2004) defined that one of its advantages is the facility to characterize the terrestrial cover and its changes, associated to land management, due to data's spatial resolution. And according to USGS (2022), the accuracy of Landsat 8/OLI achieves 90% of reliability, considering a 12 meters circle.

Additionally, the terrestrial mosaic's MNDWI on Poço da Cruz reservoir was visualized in different dates (12/06/2000, 12/10/2013, and 10/10/2020) by Leonardo et al. (2021) with a similar dynamic to that observed in this work. The study above evidentiated a temporal variability of 13 years and 7 years, where the authors analyzed the temporal spectrum perspective and detected a superficial area raise on the reservoir over the years, reinforcing that the years 2000 and 2013 indicate a higher hydric stress, due to low pluviometric indexes identified, which caused a reduction in MNDWI values.

Figure 4 represents the spatial-temporal variability of the water masks in the period from 2015 to 2020, where such procedure was a result of pixel extraction represented by MNDWI > 0. It must be noted that the visualization of hydric areas, overlapped and differentiated by color categories, portrayed the real situation of hydric condition on Poço da Cruz reservoir, evidencing a bigger hydric collapse in 2017 (yellow), differently from the hydric input in 2020 (blue). However, it must be highlighted that the period from 2015 to 2019 was considered critical throughout the Northeast in the hydric point of view, with low pluviometric indexes (Rossato et al., 2017; Souza et al., 2018).

As seen in Figure 5, relative to water pixel quantities and hydric areas resulting from MNDWI's modeling on Landsat 8/OLI images, it was observed that the superficial water on Poço da Cruz reservoir diminished approximately 0.86 km² between 2015 and 2016 and 1.4 km² between 2016 and 2017. The most significant changes in the reservoir area were detected in 2017 and 2020. Especially observed in 2017, there was a decrease that affected 1.61 km² in its total superficial area (Figure 5); in percentage terms, the reservoir had 1.63% of its usable volume (ANA, 2022), corroborating the results in this study.

Between 2017 and 2018, according to Figure 5, there was a rise of approximately 5 km² in superficial area, evidencing the expansion of flooded area on the hydric body. From 2018 to 2019 there was no expressive area difference in spatial distribution, but, in quantitative terms, it was possible to observe an increase of 0.45 km². The year 2020 was the period when the superficial water reached the highest values compared to other studied years (34.52 km²), evidencing, expressively, a remarkable rise in the flooded areas on the reservoir as well visualized in Figure 4. These results supported the research developed by the INPE (2022) when they estimated the superficial area of Poço da Cruz from 2012 to 2017 through Landsat 8 images; it was evidenced that 2017 presented similarities with the hydric body configuration of this research.

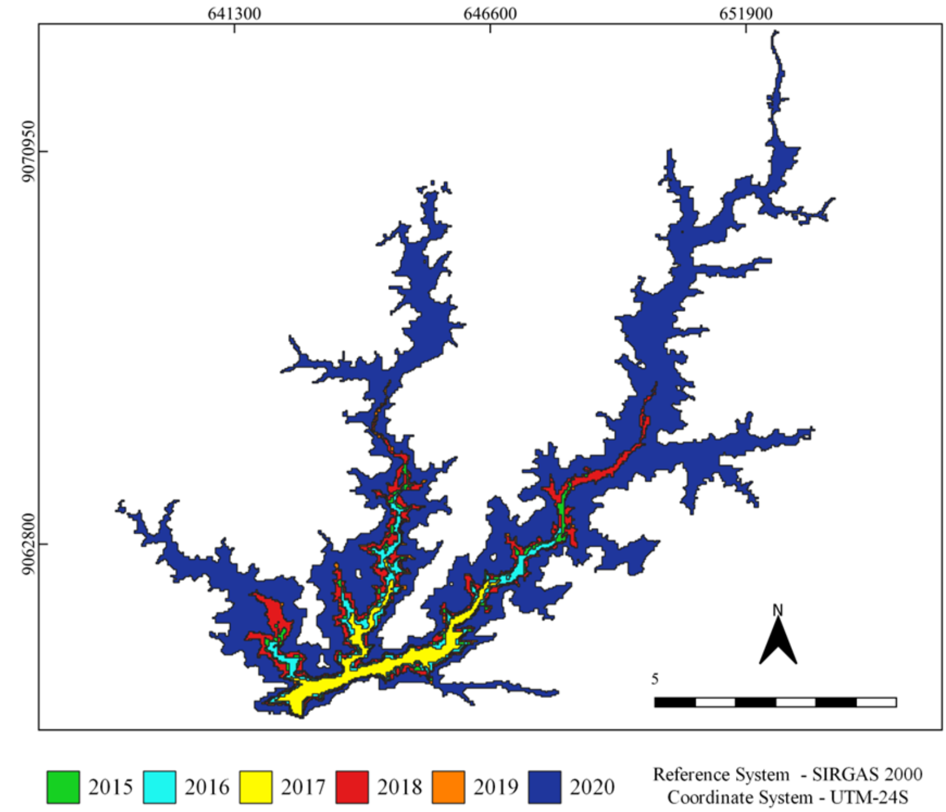
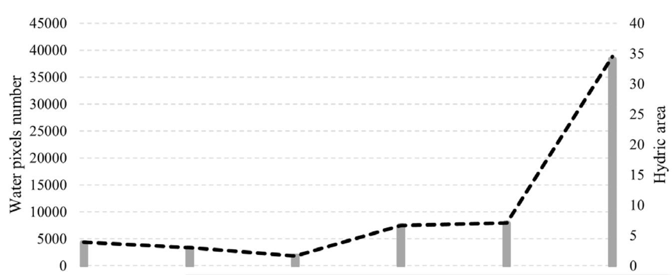


Figure 4 – Temporal variability of the water area of the Poço da Cruz reservoir, Pernambuco, from 2015 to 2020.



	10/29/2015	10/15/2016	10/20/2017	10/21/2018	10/24/2019	10/26/2020
Water pixels number	4296	3349	1799	7393	7888	38362
Hydric area (km²)	3.87	3.01	1.61	6.65	7.1	34.52

Figure 5 – Amount of pixels containing water and hydric areas (km²) resulting from the MNDW modeling in Landsat 8/OLI images.

The influence of rainy events as the hydric entrance on the mirror's water expression of the reservoir was considerably significant when the georeferenced spatiality of CHIRPS product (Figure 2) is compared to MNDWI (Figure 3). Focusing the year 2017 (Figure 5), which presented the lowest amount of water pixels (1,799 pixels) and hydric area (1.61 km^2), it was correspondent to pixels presence in red color on the reservoir's area that equal to a pluviometric index of 2 mm (Figure 2, October 2017). This result is expected, considering that the precipitation represents the via that promotes a rise in the reservoir hydric volume. On rainy periods, the water mirror rises in area terms, but on dry periods, due to high evapotranspiration, its area reduces markedly, a fact confirmed by MNDWI variation.

It is also emphasized that the efficiency of CHIRPS product was highlighted by Silva et al. (2020) when the performance of product's precipitation estimative to sub-basin of Apau River, Castanhal (PA) was analyzed. The results evidenced that the CHIRPS achieved to replicate with good precision the seasonal variability of precipitation on the region of interest, with significatively correlations varying between 0.86 and 0.99 with pluviometers data. The CHIRPS good precision also was confirmed all over Brazil through extensive validation campaigns, including Pernambuco, in a way that the product data are indicated to be used in different purposes, including to evaluate extreme events and climate changes (Costa et al., 2019).

It is important to point out that the increase of the reservoir's hydric area gains contribution not only by the rain of October month, which corresponds to the period here evaluated, but also in the previous months. In addition, the precipitation data over the basin, referring to the months of Landsat image acquisitions, indicate the influence of the estimated precipitation by CHIRPS in the reservoir hydric dynamics.

Conclusions

The MNDWI spectral index modeled and georeferenced with Landsat 8/OLI satellite system data allowed to detect the superficial areas on Poço da Cruz reservoir, Ibimirim (PE), Brazil, evidenced the spatial-temporal changes, and provided an elaborated delimitation of hydric body on October months in the years 2015, 2016, 2017, 2018, 2019, and 2020.

The MNDWI was compatible with estimated precipitation data by CHIRPS product, in which the spatial correlation between the rainy event occurrence and the hydric area delimitation was evidenced, especially, in October 2017 (minimum values) and October 2020 (maximum values).

Thereby, the georeferenced modeling of MNDWI spectral index, with Landsat 8/OLI Satellite orbital data, allied with CHIRPS product is a rewarding methodology, with easy application and fast processing, in which is provided efficiency on hydric areas delimitation in Brazil's semiarid. This monitoring type, mainly when is realized in continuous form, is essential for the hydric management and decision making, assisting, moreover, on the strategies adoption of productive conveniences with the droughts and serving as an alternative and additional data source to the regional, state, or national hydric managers.

Acknowledgment

The authors thank the United States Geological Survey (USGS) for the acquisition of satellite's images.

Contribution of authors:

ALMEIDA, D. N. O.: Conceptualization; Data curation; Investigation; Methodology; Formal Analysis; Writing — Original Draft. ARAÚJO, D. C. S.: Formal Analysis; Writing — Review & Editing. SOARES, D. R.: Writing — Review & Editing. MAIA, F. M. A.: Writing — Review & Editing. MONTENEGRO, S. G. L.: Formal Analysis; Writing — Review & Editing. SANTOS, S. M.: Formal Analysis; Writing — Review & Editing. OLIVEIRA, L. M. M.: Supervision; Formal Analysis; Writing – Review & Editing.

References

Agência Nacional de Águas e Saneamento Básico (ANA). Portal. ANA (Accessed July, 2022) at:. https://www.ana.gov.br.

Agência Pernambucana de Águas e Climas (APAC). Sistema de Informação Geográfica. APAC (Accessed Nov, 2022) at:. https://www.apac.pe.gov.br/.

Alesheikh, A.A.; Ghorbanali, A.; Nouri, N., 2007. Coastline change detection using remote sensing. International Journal of Environmental Science & Technology, v. 4, 61-66. https://doi.org/10.1007/BF03325962.

Almeida, D.N.O.; Salgueiro, C.O.B.; Chaves, J.V.; Santos, S.M.; Oliveira, L.M.M., 2021. Spectral indices in the detection of water bodies using images from the MSI - Sentinel 2 sensor. Journal of Hyperspectral Remote Sensing, v. 11, (2), 125-135. https://doi.org/10.29150/jhrs.v11.2.p125-135.

Araújo, D.C.S.; Montenegro, S.M.G.L.; Corbari, C.; Viana, J.F.S., 2021. Calibration of FEST-EWB hydrological model using remote sensing data in a climate transition region in Brazil. Hydrological Sciences Journal, v. 66, (3), 513-524. https://doi.org/10.1080/02626667.2021.1881100.

Bai, L.; Shi, C.; Yang, Y.; Wu, J., 2018. Accuracy of CHIRPS satellite-rainfall products over mainland China. Remote Sensing, v. 10, (3), 362. https://doi.org/10.3390/rs10030362.

Bayissa, Y.; Tadesse, T.; Demisse, G.; Shiferaw, A., 2017. Evaluation of satellite based rainfall estimates and application to monitor meteorological drought for the Upper Blue Nile Basin, Ethiopia. Remote Sensing, v. 9, (7), 669. https://doi.org/10.3390/rs9070669.

Climate Hazards Group InfraRed Precipitation with Station Data (CHIRPS). Portal. CHIRPS (Accessed July, 2022) at:. https://www.chc.ucsb.edu/data/chirps.

Cohen, W.B.; Goward, S.N., 2004. Landsat's role in ecological applications of remote sensing. BioScience, v. 54, (6), 535-545. https://doi.org/10.1641/0006-3568(2004)054[0535:LRIEAO]2.0.CO;2.

Corrêa, K.A.B., 2020. Estimativa de precipitação pluvial por satélites para o estado do Mato Grosso. Dissertação de Mestrado em Engenharia de Sistemas Agrícolas. Universidade de São Paulo, Piracicaba. https://doi.org/10.11606/D.11.2020.tde-12012021-104910.

Costa, J.; Pereira, G.; Siqueira, M.E.; Cardozo, F.; Silva, V.V., 2019. Validação dos dados de precipitação estimados pelo CHIRPS para o Brasil. Revista Brasileira de Climatologia, v. 24, 228-243. https://doi.org/10.5380/abclima.v24i0.60237.

Dembélé, M.; Zwart, S.J., 2016. Evaluation and comparison of satellite-based rainfall products in Burkina Faso, West Africa. International Journal of Remote Sensing, v. 37, (17), 3995-4014. https://doi.org/10.1080/01431161.2016.1207258.

Du, Z.; Linghu, B.; Ling, F.; Li, W.; Tian, W.; Wang, H.; Gui, Y.; Sun, B.; Zhang, X., 2012. Estimating surface water area changes using time-series Landsat data in the Qingming River basin, China. Journal of Applied Remote Sensing, v. 6, (1), 063609. https://doi.org/10.1117/1.JRS.6.063609.

Duan, Y.; Zhang, Y.; Ling, F; Wang, Q.; Li, W.; Li, X., 2016. Water bodies' mapping from Sentinel-2 imagery with Modified Normalized Difference Water Index at 10-m spatial resolution produced by sharpening the SWIR band. Remote Sensing, v. 8, (4), 354. https://doi.org/10.3390/rs8040354.

El-Asmar, H.M.; Hereher, M.E., 2011. Change detection of the coastal zone east of the Nile Delta using remote sensing. Environmental Earth Sciences, v. 62, 769-777. https://doi.org/10.1007/s12665-010-0564-9.

Erazo, B.; Bourrel, L.; Frappart, F.; Chimborazo, O.; Labat, D., Dominguez-Granda, L.; Matamoros, D.; Mejia, R., 2018. Validation of Satellite Estimates (Tropical Rainfall Measuring Mission, TRMM) for Rainfall Variability over the Pacific Slope and Coast of Ecuador. Water, v. 10, (2), 213. https://doi.org/10.3390/w10020213.

Feng, M.; Sexton, J.O.; Channan, S.; Townshend, J.R., 2015. A global, high-resolution (30-m) inland water body dataset for 2000: first results of a topographic–spectral classification algorithm, International Journal of Digital Earth, v. 9, (2), 113-133. https://doi.org/10.1080/17538947.2015.1026420.

Fernandes, R.R.; Nunes, G.M.; Silva, T.S.F., 2012. Classificação orientada a objetos aplicada na caracterização da cobertura da terra no Araguaia. Pesquisa Agropecuária Brasileira, v. 47, (9), 1251-1260. https://doi.org/10.1590/S0100-204X2012000900010.

Funk, C.; Peterson, P.; Landsfeld, M.; Pedreros, D.; Verdin, J.; Shukla, S.; Husak, G.; Rowland, J.; Harrison, L.; Hoell, A.; Michaelsen, J., 2015. The climate hazards infrared precipitation with stations: a new environmental record for monitoring extremes. Scientific Data, v. 2, 150066. https://doi.org/10.1038/sdata.2015.66.

Guglielmeli, A.C.O.; Silva, S.M.L.; Strauch, J.C.M., 2018. Análise multitemporal do grau de antropização da área de proteção ambiental municipal do Rio Uberaba, Uberaba, MG. Brazilian Journal of Environmental Sciences (Online), (48), 114-127. https://doi.org/10.5327/Z2176-947820180331.

Guo, H.; Bao, A.; Liu, T.; Ndayisaba, F.; He, D.; Kurban, A.; Maeyer, P., 2017. Meteorological drought analysis in the Lower Mekong Basin using satellite-based long-term CHIRPS product. Sustainability, v. 6, (9), 901. https://doi.org/10.3390/su9060901.

Instituto Nacional de Pesquisas Espaciais (INPE) (Accessed Aug, 2022) at:. http://geopro.crn.inpe.br/.

Jeihouni, M.; Toomanian, A.; Kazem, S.; Alavipanah; Hamzeh, S., 2017. Quantitative assessment of Urmia Lake water using spaceborne multisensor data and 3D modeling. Environmental Monitoring and Assessment, v. 189, 572. https://doi.org/10.1007/s10661-017-6308-5.

Klein, I.; Gessner, U.; Dietz, A.J.; Kuenzer, C., 2017. Global WaterPack – A 250 m resolution dataset revealing the daily dynamics of global inland water bodies. Remote Sensing of Environment, v. 198, 345-362. https://doi.org/10.1016/j.rse.2017.06.045.

Lai, Y.; Qiu, Y.; Fu, W.; Shi, L., 2013. Monitoring and analysis of surface water in Kashgar region based on TM imagery in last 10 years, Remote Sensing, v. 28, 50-57. https://doi.org/10.3969/j.issn.1000-3177.2013.03.009.

Leonardo, H.R.A.L.; Salgueiro, C.O.B.; Almeida, D.N.O.; Santos, S.M.; Oliveira, L.M.M., 2021. Sensoriamento Remoto Aplicado na Geoespacialização do Reservatório Poço da Cruz - PE e seu Entorno. Revista Brasileira de Geografia Física, v. 14, (6), 3592-3607. https://doi.org/10.26848/rbgf.v14.6.p3614-3629.

Lu, S.; Ma, J.; Ma, X.; Tang, H.; Zhao, H.; Ali Baig Hasan, M., 2019. Time series of the Inland Surface Water Dataset in China (ISWDC) for 2000 – 2016 derived from MODIS archives. ISWDC. https://doi.org/10.5281/zenodo.2616035.

Luo, C.; Xu, C.; Cao, Y.; Tong, L., 2017. Monitoring of water surface area in Lake Qinghai from 1974 to 2016. Journal of Lake Science, v. 29, (5), 1245-1253. https://doi.org/10.18307/2017.0523.

Nogueira, S.M.C.; Moreira, M.A.; Volpato, M.M.L., 2018. Evaluating Precipitation Estimates from Eta, TRMM and CHIRPS Data in the South Southeast Region of Minas Gerais State - Brazil. Remote Sensing, v. 10, (2), 313. https://doi.org/10.3390/rs10020313.

Ornellas, J.L.; Caiafa, A.N.; Lopes, E.R.N, 2022. Temporal dynamics and land use in the marine protected area of Baía do Iguape in Northeastern Brazil. Brazilian Journal of Environmental Sciences (Online), v. 57, (3), 386-396. https://doi.org/10.5327/Z217694781312.

Paredes-Trejo, F.J.; Barbosa, H.A.; Lakshmi Kumar, T., 2017. Validating CHIRPS-based satellite precipitation estimates in Northeast Brazil. Journal of Arid Environments, v. 139, 26-40. https://doi.org/10.1016/j.jaridenv.2016.12.009.

Pekel, J.F.; Cottam, A.; Gorelick, N.; Belward, A.S., 2016. High-resolution mapping of global surface water and its long-term changes. Nature, v. 540, 418-422. https://doi.org/10.1038/nature20584.

Penachio, S.M.; Oliveira, S.A.S.; Tagliarini, F.S.N.; Barros, A.C., 2020. Índices radiométricos para estimativa de umidade do solo. Brazilian Journal of Development, v. 6, (5), 29540-29549. https://doi.org/10.34117/bjdv6n5-418.

Rokni, K.; Ahmad, A.; Selamat, A.; Hazini, S., 2014. Water feature extraction and change detection using multitemporal landsat imagery. Remote Sensing, v. 6, (5), 4173-4189. https://doi.org/10.3390/RS6054173.

Rossato, L.; Marengo, J.A.; Angelis, C.F.; Pires, L.B.M.; Mendiondo, E.M., 2017. Impact of soil moisture over Palmer Drought Severity Index and its future projections in Brazil. Brazilian Journal of Water Resources, v. 22, e36. htt ps://10.1590/2318-0331.0117160045.

Silva, B.B.; Braga, A.C.; Braga, C.C.; Oliveira L.M.M.; Montenegro, S.M.G.L; Barbosa Júnior, B., 2016. Procedures for calculation of the albedo with OLI-Landsat 8 images: Application to the Brazilian semi-arid. Revista Brasileira de Engenharia Agrícola e Ambiental, v. 20, (1), 3-8. https://doi.org/10.1590/1807-1929/agriambi.v20n1p3-8.

Silva, E.R.M.; Barbosa, I.C.C.; Silva, H.J.F.; Costa, L.G.S.; Rocha, E.J.P., 2020. Análise do Desempenho da Estimativa de Precipitação do Produto CHIRPS para Sub-Bacia do Rio Apeú, Castanhal-PA. Revista Brasileira de Geografia Física, v. 13, (3), 1094-1105. https://doi.org/10.26848/rbgf.v13.3.p1094-1105.

Singh, K.V.; Setia, R.; Sahoo, S.; Prasad, A.; Pateriya, B., 2015. Evaluation of NDWI and MNDWI for assessment of waterlogging by integrating digital elevation model and groundwater level. Geocarto International, v. 30, (6), 650-661. https://doi.org/10.1080/10106049.2014.965757.

Song, C.; Huang, B.; Ke, L.; Richards, K. S., 2014. Remote sensing of alpine lake water environment changes on the Tibetan Plateau and surroundings: A review. ISPRS Journal of Photogrammetry and Remote Sensing, v. 92, 26-37. https://doi.org/10.1016/j.isprsjprs.2014.03.001.

Souza, A.; Neto, A.; Rossato, L.; Alvalá, R.; Souza, L., 2018. Use of SMOS L3 Soil Moisture Data: Validation and Drought Assessment for Pernambuco State, Northeast Brazil. Remote Sens (Basel), v. 10, (8), 1314. https://doi.org/10.3390/rs10081314.

Taravat, A.; Rajaei, M.; Emadodin, I.; Hasheminejad, H.; Mousavian, R.; Biniyaz, E., 2016. A spaceborne multisensory, multitemporal approach to monitor water level and storage variations of lakes. Water, v. 8, (11), 478. https://doi.org/10.3390/w8110478.

Toté, C.; Patricio, D.; Boogaard, H.; Van Der Wijngaart, R.; Tarnavsky, E.; Funk, C., 2015. Evaluation of satellite rainfall estimates for drought and flood monitoring in Mozambique. Remote Sensing, v. 7, (2), 1758-1776. https://doi.org/10.3390/rs70201758.

Tulbure, M.G.; Broich, M.; Stehman, S.V.; Kommareddy, A., 2016. Surface water extent dynamics from three decades of seasonally continuous Landsat time series at subcontinental scale in a semi-arid region. Remote Sensing of Environment, v. 178, 142-157. https://doi.org/10.1016/j.rse.2016.02.034.

United States Geologic Survery (USGS). Catálogo USGS. USGS (Accessed Nov, 2022) at:. https://earthexplorer.usgs.gov/.

Verpoorter, C.; Kutser, T.; Seekell, D.A.; Tranvik, L.J., 2014. A global inventory of lakes based on high-resolution satellite imagery, Geophysical Research Letters, v. 41, (18), 6396-6402. https://doi.org/10.1002/2014GL060641.

Xu, H., 2006. Modification of normalized difference water index (NDWI) to enhance open water features in remotely sensed imagery. International Journal of Remote Sensing, v. 27, (14), 3025-3033. https://doi.org/10.1080/01431160600589179.

Wan, W.; Long, D.; Hong, Y.; Ma, Y.; Yuan, Y.; Xiao, P.; Duan, H.; Han, Z.; Gu, X., 2016. A lake dataset for the Tibetan Plateau from the 1960s, 2005, and 2014, Science Data, v. 3, 160039. https://doi.org/10.1038/sdata.2016.39.

Zhang, G.; Li, J. Schwatke Zheng, G., 2017. Lake-area mapping in the Tibetan Plateau: an evaluation of data and methods. International Journal of Remote Sensing, v. 38, (3), 742-772. https://doi.org/10.1080/01431161.2016.1271478.

Zhang, H.K.; Roy, D.P.; Yan, L.; Li, Z.; Huang, H.; Vermote, E.; Skakun, S.; Roger, J.C., 2018. Characterization of Sentinel-2A and Landsat-8 top of atmosphere, surface, and nadir BRDF adjusted reflectance and NDVI differences. Remote Sensing of Environment, v. 215, 482-494. https://doi.org/10.1016/j.rse.2018.04.031.