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ASSESSMENT OF THE WATER VOLUME STORAGE IN RESERVOIRS FROM THE BRAZILIAN SEMIARID REGIONS

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ABSTRACT

Semiarid regions comprise a significant portion of the Earth and they are characterized by lack of water resources. Due to low water availability, surface water is commonly stored in small reservoirs that serve as a primary source of water supply and agriculture. The water volume stored in these reservoirs may be estimated by use of area-volume model, which estimates the volume per flooded area of the reservoir. The area of reservoirs can be easily estimated by computation of Normalized Difference Water Index (NDWI) using satellite imagery. Because of the vital importance of water availability estimation in small to medium reservoirs (0.1 to 15 Km^2) of the Brazilian semiarid region, the suitability of some previous area-volume models developed for semiarid was evaluated. Additionally, a new area-volume model valid for the Brazilian semiarid region was developed using non-linear regressions. The fitted model provides estimates close to the measured volumes, indicating the ability of these models to predict the volume of water in these reservoirs. The proposed model was applied to evaluate the change of stored water in a watershed in the Brazilian semiarid region, allowing to verify a substantial reduction in the water volume during a prolonged drought. Consequently, this work points out useful strategies to monitor the water availability in the Brazilian semiarid region.

Keywords: Small water reservoirs. Water Remote Sensing. Water availability. NDWI. Area-volume model.

AVALIAÇÃO DO VOLUME DE ARMAZENAMENTO DE ÁGUA EM RESERVATÓRIOS DO SEMIÁRIDO BRASILEIRO

RESUMO

As regiões semiáridas compreendem uma porção significativa da Terra e são caracterizadas pela deficiência de recursos hídricos. Devido à baixa disponibilidade de água, a água superficial é comumente armazenada em pequenos reservatórios que servem como fonte primária de abastecimento de água e agricultura. O volume de água armazenado nesses reservatórios pode ser estimado a partir do modelo área-volume, que estima o volume por área inundada do reservatório. A área dos reservatórios pode ser quantificada empregando o Índice de Água por Diferença Normalizada (NDWI) usando imagens de satélite. Devido à vital importância das estimativas dos volumes de água armazenadas em reservatórios pequenos e médios (0,1 to 15 Km^2) do semiárido brasileiro, a consistência de alguns modelos área-volume anteriores desenvolvidos para o semiárido foi avaliada. Adicionalmente, um novo modelo área-volume válido para o semiárido brasileiro foi elaborado a partir de regressões não-lineares. O modelo ajustado fornece estimativas próximas aos volumes medidos, indicando a capacidade desses modelos de prever o volume de água nesses reservatórios. O modelo produzido foi utilizado para avaliar a variação da água armazenada em uma bacia hidrográfica do semiárido brasileiro e permitiu verificar uma redução substancial do volume de água durante uma seca prolongada. Consequentemente, o presente trabalho aponta estratégias úteis para monitorar a disponibilidade no semiárido brasileiro.

Palavras-chave: Pequenos reservatórios de água. Sensoriamento Remoto da água. Disponibilidade de água. NDWI. Modelo área-volume.

INTRODUCTION

Nearly 2.5 billion people worldwide live in arid and semiarid regions, which cover a total surface area of approximately 41% of Earth's surface (GAUR and SQUIRES, 2018). These regions are considered vulnerable due to the extreme unpredictability of weather conditions, which control water availability (e.g., HAZBAVI et al., 2018; AKBAS et al., 2020). Moreover, more than half of the dryland's expansion has occurred in semiarid regions since the 1960s, induced by climate changes (HUANG et al., 2016). The expansion of drylands intensified the unavailability of water resources, strongly affecting the populations living in these regions.

Due to the scarcity of water resources in semi-arid or arid regions, the damming of permanent or intermittent rivers has been established as the main strategy to improve the availability of freshwater in these regions (e.g., DUKER et al., 2020; YUFRU et al., 2020; DOS ANJOS and CABRAL, 2021; CHINNASAMY et al., 2021). Consequently, in several cases small reservoirs consist of the exclusive source of water resource for agricultural irrigation and domestic use, comprising an important driver of food security, especially during the prolonged dry periods in semiarid regions (e.g., MUGABE et al., 2003; MASIH et al., 2009; FARAMARZI et al., 2017).

To assess the volume of water stored in natural or human-built reservoirs, different approaches based on the use of remote sensing techniques have been proposed (e.g., GAO et al., 2012; LU et al., 2013; CAI et al., 2016, DEUTSCH and ALAMEDDINE, 2018). Large proportion of these studies had been conducted in semiarid regions where water resources are scarce (e.g., LIEBE et al., 2005; PEREIRA et al., 2019; MADY et al., 2020). Currently, the great part of the methods used for identifying and delimiting reservoirs using remote sensing techniques are intermediated by calculating the Normalized Difference Water Index (NDWI) developed by McFeeters (1996) or by the Modified Normalized Difference Water Index (MNDWI) developed by Xu (2006). NDWI and MNDWI are based on the normalized difference in the absorption and reflection of light between the water and other targets in different frequency ranges (MCFEETER, 1996; XU, 2006).

After the computation of the flooded areas of reservoirs by the remote sensing technique, the estimation of the volume of water stored at a specific time in reservoirs may be achieved by using a common approach based on an empirical area-volume model (e.g., LEHNER and DÖLL, 2004; RAN and LU, 2012; VAN BEMMELEN et al., 2016; CAI et al., 2016; CUNHA et al., 2020). Due to the geometry of the reservoir, the area-volume relationship may be described by a standard potency equation (Eq. 1), in which the volume (V) may be estimated from the flooded area (A) using a coefficient "a" and an exponent "b" (LEHNER et al., 2011).

$$V = a \cdot A^b \qquad (1)$$

According to Liebe et al. (2005), the exponent "b" is a parameter related to the geometry of the valley reservoir and it is expected to have a value close to 1.5. However, distinct values of "a" and "b" are found to be ranging from 0.98 to 1.46 in the literature (e.g., LIEBE et al., 2005; LEHNER and DÖLL, 2004; RAN and LU, 2012; VAN BEMMELEN et al., 2016; CAI et al., 2016, CUNHA et al., 2020).

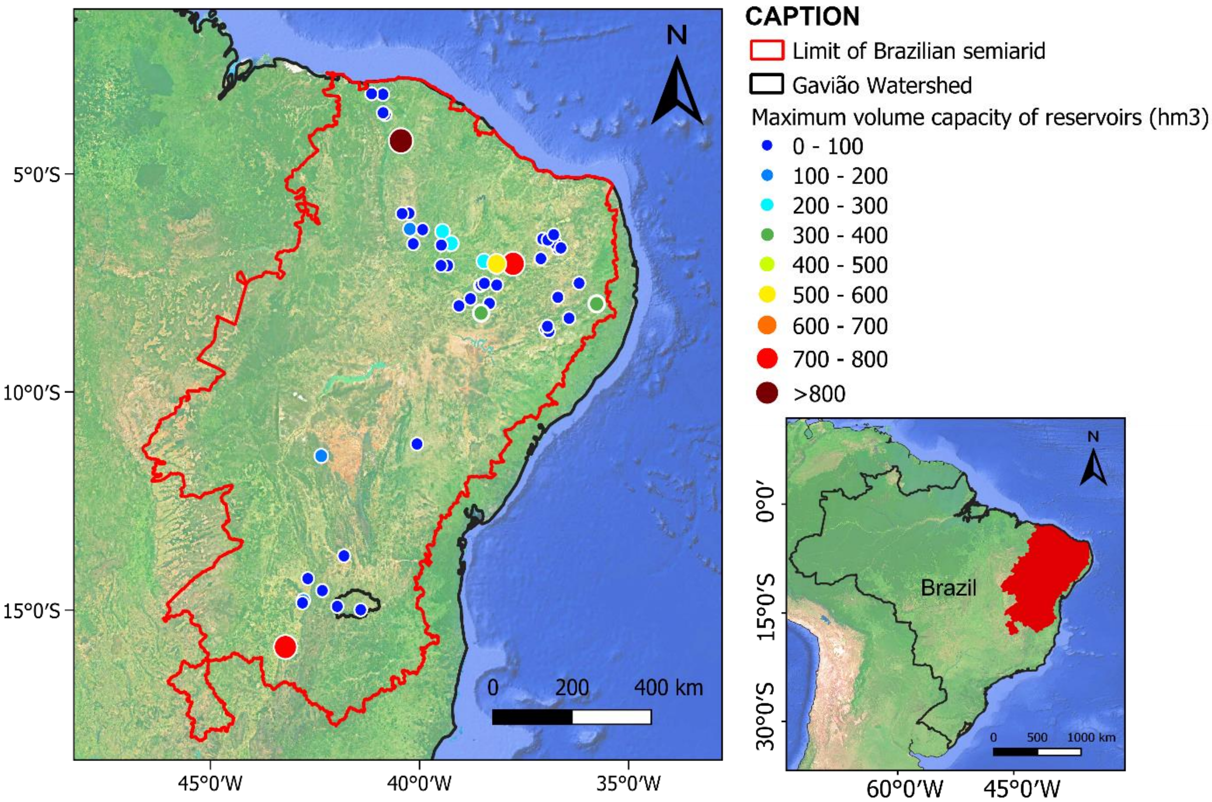
A significant portion of Brazilian territory is covered by semiarid regions where the scarcity of water affects the living population in these regions, imposing a solid limit on socio-economic development. Due to the dependency of a large proportion of the people living in the Brazilian semiarid areas on the reservoirs, an accurate assessment of the actual volume of the water storage of these reservoirs is crucial to the sustainable use of this resource. While the most important reservoirs are consistently monitored by the Instituto Nacional do Semiárido (INSA), several small to medium reservoirs are not accounted for, generating a severe gap of information. Volume estimation from reservoir area derived from NDWI or MNDWI processing comprise a low-cost and effective tool for monitoring surface water availability, serving as an attractive monitoring tool. However, no systematic work has been devoted to developing similar models in Brazilian semiarid. Thus, due to vital importance of small reservoirs of the Brazilian semiarid areas as their source of water supply and agriculture, our work aimed to improve the quantification of water availability in the Brazilian semiarid, testing the suitability of different previous area-volume models developed for semiarid regions worldwide. Further, this work also aimed to develop and test a new area-volume model specific to Brazilian semiarid derived from non-linear regression.

METHODOLOGY

Study Area

The Brazilian semiarid region covers 1,069,565.71 km^2, which corresponds to 12.6 % of the Brazilian territory (Figure 1), comprising 1,262 municipalities and 26.5 million inhabitants (SUDENE, 2017). This region is characterized by annual accumulated rainfall values below 800 mm/year, a Thornthwaite aridity index value below 0.50, and a water deficit of above 60% (SUDENE, 2017).

Figure 1 - Brazilian Semi-arid: Limits of Brazilian semiarid and the location of 48 reservoirs used in the present study. The location of Gavião Watershed is also presented 2021.



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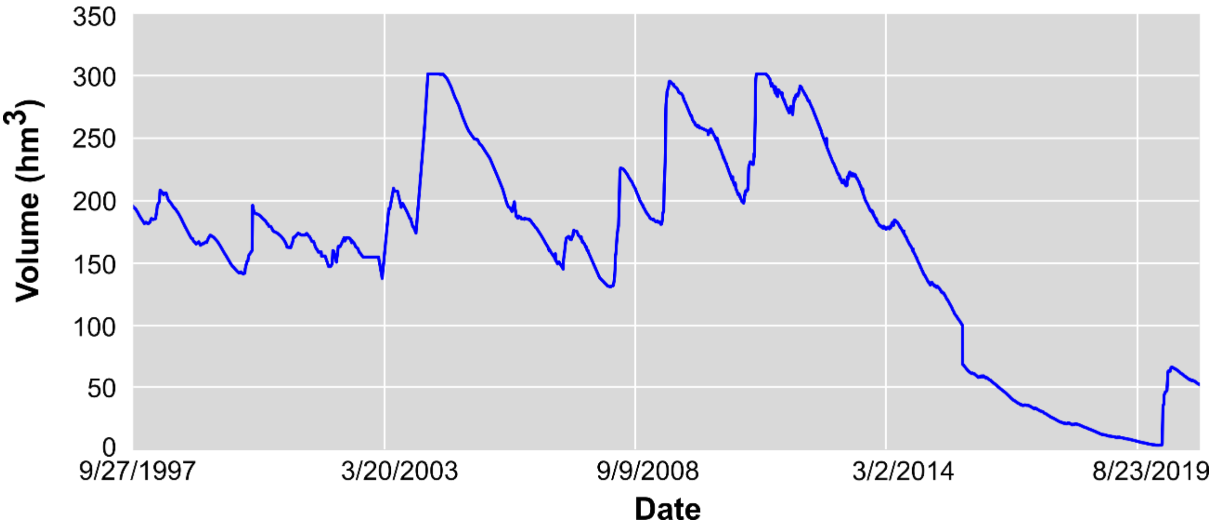
Reservoir volume records

To obtain the recorded temporal variation volume of reservoirs of the studied area, we consulted the database of INSA that consistently monitors 452 reservoirs in the Brazilian semiarid region. In our work, we acquired 293 records from 48 reservoirs scattered within the Brazilian semiarid region, as exemplified in Figure 2. Importantly, a very intense drop was observed from the year 2014 in practically all the evaluated reservoirs, as exemplified in this figure. As the main criterion, we gathered the dataset in distinct geological (crystalline basement, sedimentary basins) and geomorphological contexts, prioritizing reservoirs with detailed monitoring. Due to the considerable variation in the scales, we restricted our analysis to values of flooded areas ranging from 0.1 to 15 km^2.

Figure 2 - Example of volume variation over time in a reservoir acquired from the INSA database.



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Imagery acquisition and NDWI calculation

The Sentinel-2 satellite belongs to the Global Monitoring Program for Environment and Security (GMES), administered by the European Community and the European Space Agency (ESA). In the present study, the analysis was performed using images from the 29SQA tile (Sentinel-2 mission grid system). We collected images from Sentinel-2 in close periods (±5 days) of periods with measurement of reservoir volumes. The raw images obtained corresponded to Level 1C (L1C) products in the Top of Atmosphere (TOA). In total, we acquired 86 scenes.

Using the Sen2Cor algorithm (MALENOVSKÝ et al., 2012), all acquired images were processed to perform the atmospheric correction processing the images at Level 1C Atmosphere TOA (Level 1), providing Level 2A Atmosphere and Level 2A (BOA) reflectance. The algorithm is based on a set of 24 LUT (Look Up Table), which covers most terrestrial atmospheric conditions and recreates values to generate an image through atmospheric correction processing.

The Normalized Water Difference Index (NDWI) represents a method developed to delineate bodies of water on the surface from digital images obtained by remote sensing. According to McFeeters (1996), NDWI uses radiation reflected in the near infrared and visible green lights to identify water and its distinction in relation to soil and terrestrial vegetation. Since the water reflectance from the visible to the infrared range is gradually weakened, the surface water in an image can be delineated with the NDWI indices by the contrast between the visible wavelength and the near-infrared and wavelengths short. NDWI is calculated from Equation 2.

$$NDWI = \frac{(\rho_{GREEN} - \rho_{NIR})}{(\rho_{GREEN} + \rho_{NIR})} \qquad (2)$$

Where ρ_{GREEN} represents the green band (band 3 in the Sentinel-2) and ρ_{NIR} is the nearer infrared band (band 8 in the Sentinel-2). This equation generates pixel values that vary in scale from -1 to 1, where values of NDWI≥0 represent water, and NDWI <0 represent soil and vegetation. By NDWI images we define the lateral extension of the reservoir with a resolution of 10 x 10 m.

In order to verify the adequateness of the NDWI calculation to identify the surficial water bodies, we conducted a visual inspection of the NDWI classification with RGB true color images produced by the same images of Sentinel-2 used to calculate the NDWI. A few identified inconsistencies were corrected.

Small reservoir areas derived from NDWI

All the produced NDWI images were cut close to the reservoir limits to prevent the computation of neighboring surficial water bodies. Subsequently, the images were converted into a shapefile point . The reservoir area (A) was calculated by multiplying the number of pixels classified as water (i.e., NDWI index ≥0) by the pixel area of the Sentinel-2 image, i.e., 100 m2 (Equation 3). The calculated NDWI values were classified in the ascending order to identify NDWI values between 0 and 1, an interval that indicates the occurrence of areas covered by water.

$$\mathrm{A} = \sum_{\mathrm{i}=1}^{\mathrm{n}} \mathrm{P_i} * 100 \quad (3)$$

Where n represents the number of pixels classified as water and $\mathrm{P_i}$ an individual pixel classified as water.

Evaluation of area x volume model for Brazilian semiarid region

We gathered other previously used empirical models to predict the stored water volume using the area covered by water developed in other worldwide semiarid regions. We found the models of Liebe et al. (2005), Sawunyama et al. (2006), and Mady et al. (2020), respectively Eq. 4, 5, and 6 in Table 1, as potential models that could estimate the volume of small to medium reservoirs in the Brazilian semiarid region, in response to the similarity of the climatic conditions where these studies were conducted**.** Alternatively, to obtain a site-specific area-volume model for the Brazilian semiarid region, we fitted a power function model to flooded area estimated by the NDWI index and the measured water volume. Using a non-linear regression, we adjusted the generic area-volume model (Equation 1) to compiled data and found the best-fit values of coefficients “a” and “b”.

Table 1 - Alternative tested area-volume models in our research.

Power function area x volume	Reference	Description
$V = 3.574 \cdot A^{1.4367}$ (4)	Liebe et al. (2005)	An empirical model for small reservoirs in the semiarid regions of Ghana, Western Africa.
$V = 2.122 \cdot A^{1.327}$ (5)	Sawunyama et al. (2006)	An empirical model for reservoirs in the semiarid region of Limpopo Basin, Zimbabwe.
$V = 4.148 \cdot A^{1.173}$ (6)	Mady et al. (2020)	An empirical model for small to medium reservoirs in the semiarid regions around the world.

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We assessed the suitability of all the tested models, computing the coefficient of the absolute average error (E) and RMSE (Root Mean Square Error), respectively represented by Eq. 7 and 8.

$$E(\%) = \frac{1}{n}\sum_{i=1}^{n}\left(\frac{V_{calc}-V_{obs}}{V_{obs}}\right) \cdot 100 \quad (7)$$

$$RMSE = \sqrt{\frac{\sum_{i=1}^{n}(V_{cal}-V_{obs})^2}{n}} \quad (8)$$

Where V_{cal} and V_{obs} denote the calculated and observed volume of stored water, respectively, and n represents the number of samples.

Assessing the variation of reservoirs

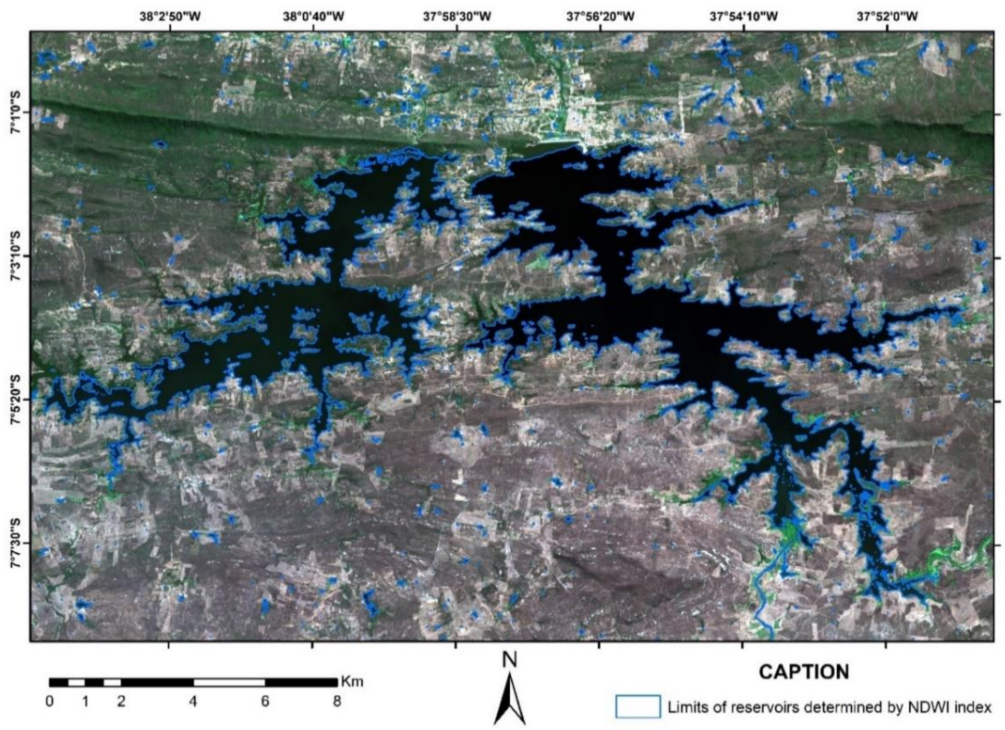
The reservoirs implanted on intermittent or perennial rivers in the same watershed are connected to the same streams network. Based on this assumption, the quantification of the total water volume stored in watershed scale is more beneficial to water management than the simple determination of volume in individual reservoirs. Hence, we applied the built power function model to determine the variation in the total water stored in the reservoirs of the Rio Gavião watershed, located in the south of Bahia state, southern region of Brazilian semiarid (Figure 1) and it has an area equivalent to 5,547.6 km^2. We selected this watershed because it is in a region where the most extended periods of drought were recorded (BRITO et al., 2017). The total water volume stored in this watershed's reservoirs was computed in August 2016 and November 2016 to estimate the variation of water losses in the reservoirs by discharge, evapotranspiration, and withdrawal for agricultural use.

RESULTS

Comparison of NDWI and true color RGB

By the processing of 293 images of Sentinel-2 imagery, we obtained the area of 48 reservoirs in the semiarid region (Figure 1) in different periods and analyzed them with the measured volumes of these reservoirs. After this, all the produced NDWI images were manually analyzed by comparison with RGB images to verify the correctness of the NDWI calculation in order to identify the water bodies in all evaluated scenes. In almost all cases, we demonstrated a complete correspondence among the areas classified as water by the NDWI index and the RGB image, as exemplified in Figure 3. Few exceptions were identified in the case of shadows of clouds or relief, in which the NDWI index was above 0 and, thus, mistakenly classified as water. Furthermore, we verified the marginal parts of some reservoirs covered by macrophyte vegetation for which the NDWI values were below 0 and, consequently, were not classified as water. Although the errors identified are potentially negligible, we have adjusted these inconsistencies when placed.

Figure 3 - Coremas (PB): Overlap of RGB true color and limit of flooded area for reservoir identified by NDWI index calculation, 2021.



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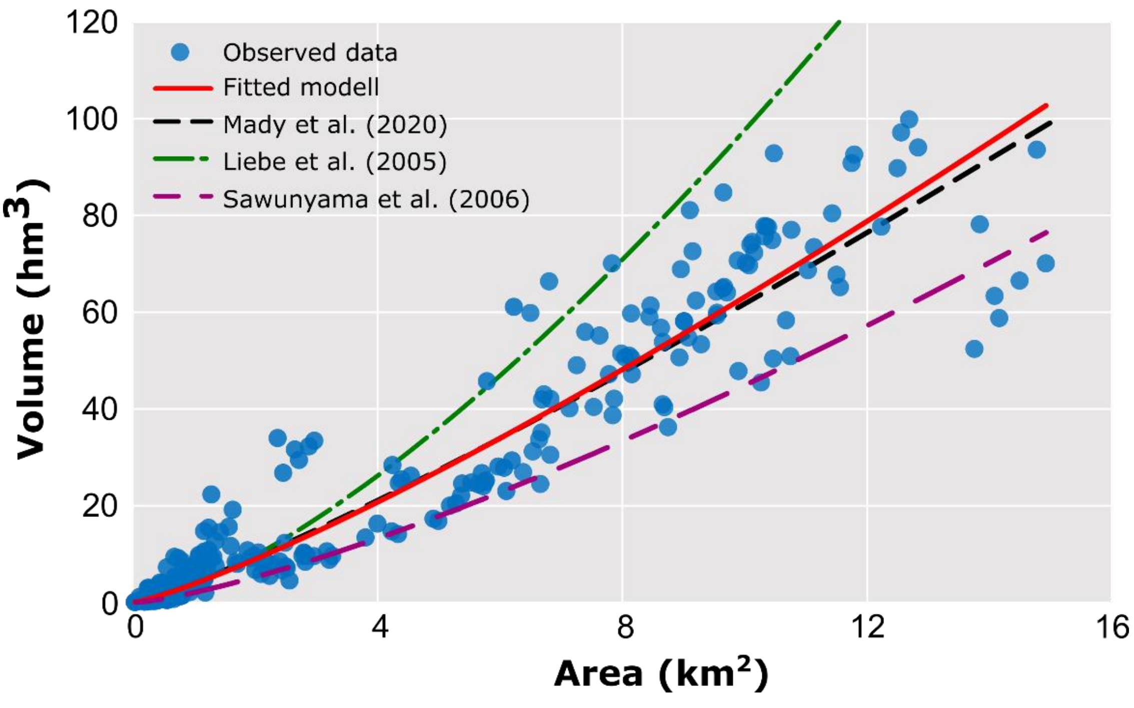
Empirical Area x volume model for the Brazilian semiarid Region

Figure 4 illustrates the scatterplot of reservoirs delimited by the NDWI index and the area calculated by Eq. 3 against the measured volume of these reservoirs, as well as the fitted power function (Eq. 1). The goodness fit of power function produced an empirical area-volume model for the Brazilian semiarid region (Eq. 9).

$$V = 3.847 * A^{1.215} \quad (9)$$

Plotting the curve of alternative power function models (see Table 1), we noted that the area versus volume curve produced by the model by Mady et al. (2020) is very close to our model, demonstrating the suitability of the former to predict the volume estimated in the Brazilian semiarid region. On the other hand, the error computation indicates that the models by Liebe et al. (2005) and Sawunyama et al. (2006) adjust partially to the evaluated samples and are not appropriate for our study area.

Figure 4 - Scatterplot of the flooded area estimated by remote sensing and a measured volume of the reservoir, and the fitted power function and curve of other previous models developed to semiarid regions.



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The computed RSME and absolute average error produced by estimates from all tested models are presented in Table 2, where it is possible to note that the average error and RMSE error of the model by Mady et al. (2020) are close to the case of our model and they are both significantly lower than other tested models. Moreover, the calculated error indicates that the model by Liebe et al. (2005) tends to overestimate, while Sawunyama et al. (2006) tend to underestimate the actual volume.

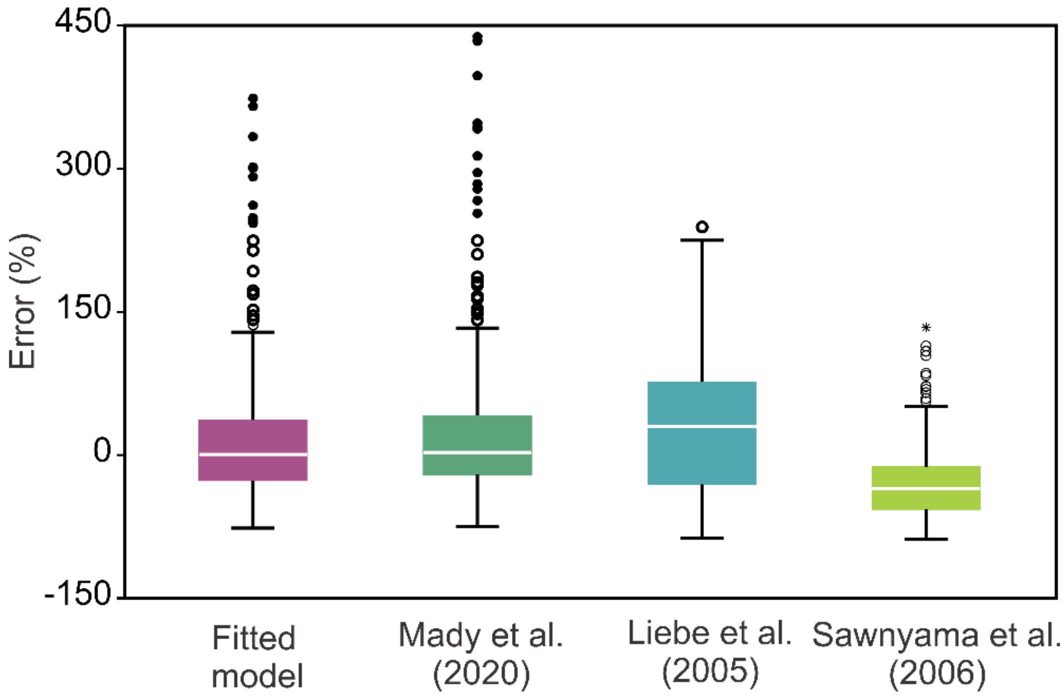
Table 2 - Comparison of R^2, RSME, and average error produced by all tested equations used to estimate the water volume of the flooded area.

Equation	R^2	RSME (hm^3)	Absolute error (%)
Fitted model	0.90	8.69	17.54
Mady et al. (2020)	0.90	8.57	24.59
Liebe et al. (2005)	0.89	26.14	29.79
Sawunyama et al. (2006)	0.90	13.19	-31.05

Source - Authors.

Figure 5 shows the boxplot of calculated errors, illustrating the distribution of computed errors, indicating that our model and Mady et al. (2020) present a median close to zero, with the first and third quartiles almost symmetrically positioned around zero. In the case of the model by Liebe et al. (2005), the median and third quartile are significantly above zero, emphasizing its tendency of overestimating the volume. Finally, in the case of the model by Sawunyama et al. (2006), the third quartile is below zero, reinforcing its propensity of underestimating the volume. Notably, our model and the one by Mady et al. (2020) present several outliers with errors above 150%, especially concerning tiny reservoirs (< 0.5 hm^3).

Figure 5 - Boxplot of error of estimation of the fitted model and alternative models. Model and lower than other models, presenting a median of error close to zero and similar RSME.



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Temporal changes of stored water

Using the NDWI index, we identified 515 reservoirs in the Gavião watershed (Figure 6), emphasizing the locations of the Anagé and Tremedal reservoirs. We computed the flooded area of small reservoirs in five different periods: August 2016, November 2016, September 2018, October 2019, and September 2020. The flooded area of each reservoir was converted in a correspondent volume by use of Eq. 9. By the sum of the volume of all the reservoirs, we estimated the total water stored in the evaluated periods.

Figure 6 - Gavião watershed, state of Bahia, Brazil: Distribution of 515 reservoirs identified in the Gavião watershed. Tremedal and Anagé, the main reservoirs in the watershed, are highlighted, 2021.

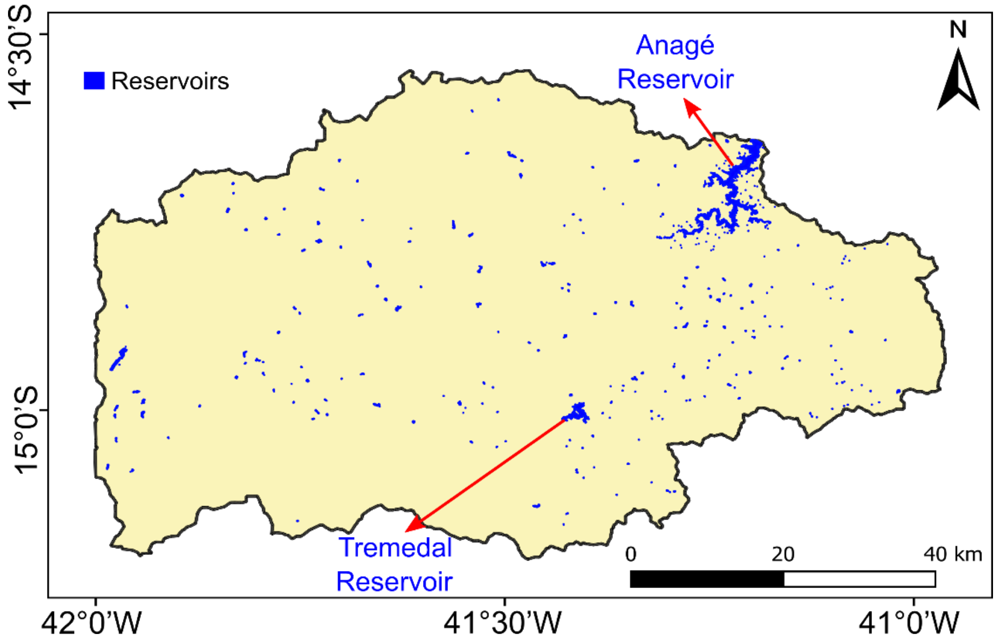

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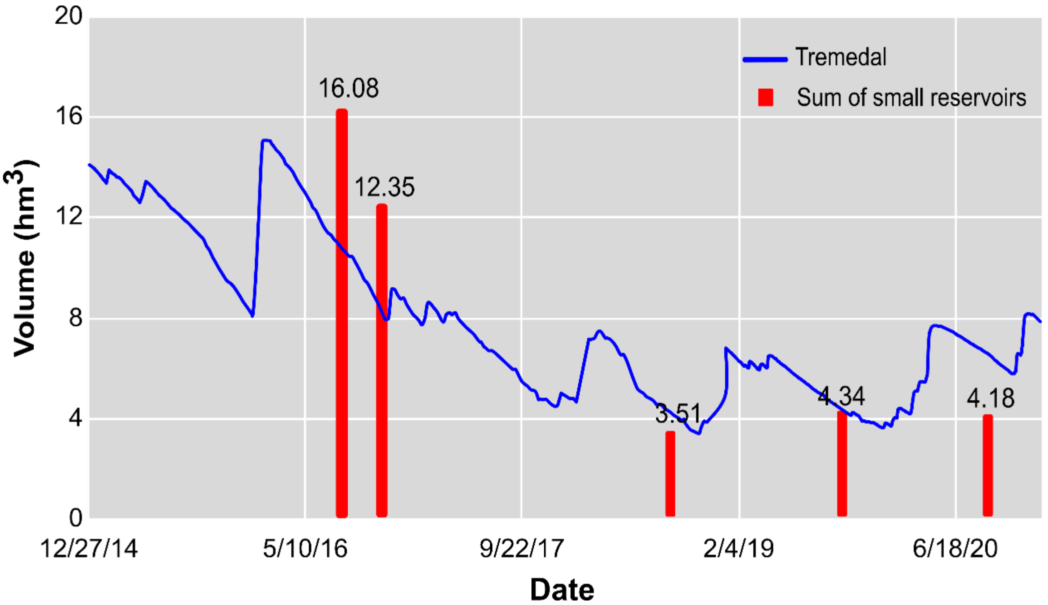
Figure 7 presents a graph showing the variation in the sum of all the small and non-monitored reservoirs in the Gavião watershed in the evaluated periods. It also offers the temporal changes of the water volume from the Tremedal reservoir, which exhibits seasonal cycles with an increase during the rainy season and a decrease during the dry seasons. The variation in the volume of the small reservoirs is proportional in magnitude with the variation recorded in the Tremedal reservoir, reinforcing some degree of interconnectedness of small and large reservoirs.

Figure 7 - Variation in the volume of the water stored in the Tremedal Reservoir and the total water stored in the small reservoirs within the Gavião Watershed.



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By comparing the water volume of the two consecutive periods, it is possible to evaluate the increase in stored water in response to the entry of rainfall during the rainy periods or its removal by evapotranspiration, discharge, and withdrawal. The estimated volumes in August and November 2016 were 16.08 hm^3 and 12.35 hm^3, respectively, which corresponds to a decrease of 23.2%. Dividing the lost volume by range time between the two measurements, we obtain a rate of loss equal to 0.041 hm^3 per day.

DISCUSSION

The semiarid region covering a large proportion of the Brazilian territory is recognized as having the poorest population in Brazil. The scarcity of water in the Brazilian semiarid region is an essential factor that hampers local socio-economic development, produces food insecurity, and impels the migratory flow of the population in this region (MARENGO et al., 2016).

As the main action to mitigate the lack of water in the semiarid region of northeastern Brazil in the last decade, a controversial channelizing part of the water flow from the São Francisco River to a part of the semiarid region was implemented. This transposition will provide water to a part of the population living in the northeastern semiarid region of Brazil, but the long-term social and economic benefits, as well as the environmental impact, are still unknown (LEE et al., 2014).

Nevertheless, elevated groundwater salinity is frequently observed in these aquifers, and total dissolved solids often exceeding 1,000 mg/L (e.g., BRITTO COSTA et al., 2006; SOUZA FILHO et al., 2010; ROJAS et al., 2020; SILVA et al., 2020). The high salinity found in shallow aquifers of Brazilian semiarid is mostly natural and related to high flux evaporation (e.g., BURTE et al., 2011; ALMEIDA and FRISCHKORN, 2015). Consequently, in many regions of Brazilian semiarid, shallow aquifers do not represent alternative sources of water for supply or agricultural uses.

Despite its limitations, the water storage in small reservoirs still represents the most sustainable and safest alternative for agricultural use in the drylands from Brazilian territory (BRASIL and MEDEIROS, 2020). For this reason, the quantification of water stored in these reservoirs and its seasonal variations are fundamentally crucial as ways of local policy. Furthermore, in some Brazilian semiarid region, economic development increased the demand for water that effective reservoir networks can only supply (MAMEDE et al., 2012). However, in most cases, this network is not planned at regional scales, but rather made by local farmers individually, in order to meet their irrigation water demands during periods of prolonged drought. Consequently, the assessment of stored water by the accumulation of runoff during the rainy seasons in small reservoirs is a crucial issue in water availability studies.

The power function adjustment (Eq. 1) still represents an approach commonly used to estimate the volume of reservoirs from their areas. However, Pereira et al. (2019) have demonstrated the limitation of this approach, overestimating the volume of water stored in the reservoirs. As an alternative, these authors presented a new approach derived from a modified shape equation based on the topography morphology of reservoirs. However, the information required to estimate the water volume based on Pereira et al. (2019) approach usually is absent. Consequently, the empirical model based on the power function still represents the most feasible way to estimate the availability of water resources.

The dataset used in our analysis encompasses distinct reservoir dimensions and distinct geological, geomorphological, and hydrological contexts had seen in the Brazilian semiarid region. Among the tested models developed to predict the water volume in semiarid regions, the equation proposed by Mady et al. (2020) offered the best fit, closely resembling our empirical area-volume model. Despite the excellent agreement of estimation, several data significantly deviated from these models by Mady et al. (2020) and our fitted model, as seen in Figure 4. This fact is not unexpected due to the diversity of scales, topography morphology, reservoir geometry, and geology contexts. Interestingly, as noted in Figure 4, the model's curve by Sawunyama et al. (2006) fits several data negatively shifting from the adjusted model curve. This suggests that some reservoirs possess similar characteristics to those observed in the semiarid regions of Zimbabwe and may effectively predict the stored water volume in these cases.

Conclusively, our work demonstrates the applicability of the remote sensing technique to provide a long-term monitoring of water stored in reservoirs from the Brazilian semiarid region. While hundreds of reservoirs are monitored, the most part of these reservoirs are not accounted for, leading to uncertainties in the estimates of water available. Thus, our model bridges this information gap by permitting us to estimate the water volume stored in small to medium reservoirs (0.1 to 100 hm^3). Therefore, our model enhances the estimates of water availability and it can be used as a criterion in water management contexts. Moreover, the use of our model allows to assess the rate of water volume lost by discharge, evapotranspiration, infiltration, and withdrawal for agricultural use, supporting the prediction of water scarcity, especially during prolonged droughts. Due to the scale of our analysis, we presume that the spatial NDWI images produced by the processing of Sentinel-2 imagery (10 m) offer the most attractive tool to detect the reservoirs in the Brazilian semiarid region.

Finally, due to the interconnectedness of the damming streams network in a watershed, the evaluation of water availability should be conducted integrating the variability of reservoirs in a watershed scale instead of taking the reservoirs at the individual level. As pointed out by Araújo and Medeiros (2013), the presence of a dense network of small reservoirs upstream of numerous small dams upstream the most important reservoirs promote positive and negative impacts on the overall water availability. Thus, we extended our model to calculate the water variation in a medium watershed by evaluating the change of stored water volume. We calculated a reduction of 3.48% in the Gavião Watershed within a time range of 4 months. We computed a rate loss of 0.052 hm^3/day based on this difference, considering natural (discharge, evapotranspiration, infiltration) and anthropic (withdraw) factors. Like the better spatial resolution present in Sentinel-2, its temporal resolution (5 days) allows a detailed temporal diagnostic of stored water in reservoirs. However, the persistent cloud cover seen in several scenes is a potential limitation recorded in the Brazilian semiarid region.

FINAL CONSIDERATIONS

The Brazilian semiarid region, characterized by water scarcity, comprises a significant proportion of the Brazilian territory and frequently faces problems with prolonged droughts. Since the water represents a vital resource to human subsistence and includes the main limiting factor to socio-economic development in this region, correct water management practices are needed. In order to contribute to the quantification of the water resources in the Brazilian semiarid region to be used for management purposes, we developed an empirical model capable of estimating the stored volume of water in small to medium reservoirs based on remote sensing techniques. Our results demonstrated the suitability of remote sensing to estimate the superficial water volume, providing an additional method to monitoring the water availability. Additionally, we demonstrated the application of the area x volume model to estimate the variation of water stored in reservoirs inside the watershed, allowing us to quantify the rate of water loss by use or natural flow and to predict the decrease of accumulated water volume in prolonged droughts, anticipating a potential water crisis.

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