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Analysis of cloud condition on Sentinel-2 MSI and Landsat-8 OLI images of a public supply lake in Belém-Pará-Brazil

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ABSTRACT

The eutrophication process leads to reduced water quality and economic losses worldwide. Furthermore, it is possible to apply remote sensing techniques for monitoring of aquatic environments. In this paper, we analysed the combined use of Sentinel-2 Multispectral Instrument and Landsat-8 Operational Land Imager data to monitor a eutrophic aquatic environment under adverse cloudy conditions, from July 2016 to July 2018. Data pre-selection was performed, and then the images were acquired for further investigation. After that, we created a key to the interpretation of cloud conditions for the study area and grouped each of 125 scenes in a Principal Component Analysis (PCA). The PCA grouped months with similarities in cloud conditions, highlighting their patterns in terms of the rainy and dry seasons for the study area. Another interesting result was that, even under the inherent adverse cloud regime of the Amazon, the combined use of both free satellite imagery data could be useful for further analyses, such as measuring of chlorophyll a, coloured dissolved organic matters, total suspended solids and turbidity. However, we highlight that, firstly, studies must be made to validate the data in situ, so that monitoring programs can be built through remote sensing applications.

Keywords: amazon waters, bolonha lake, remote sensing.

Análise das condições de nuvens em imagens Sentinel-2 MSI e Landsat-8 OLI de um lago de abastecimento público em Belém-Pará-Brasil

RESUMO

O processo de eutrofização leva à redução da qualidade da água e a perdas econômicas no mundo todo. Além disso, é possível aplicar técnicas de sensoriamento remoto para o monitoramento de ambientes aquáticos. Neste estudo, objetivou-se analisar o uso combinado dos dados Sentinel-2 Multispectral Instrument e Landsat-8 Operational Land Imager para o monitoramento de um ambiente aquático eutrofizado sob condições adversas de nuvens, de julho de 2016 a julho de 2018. Foi realizada a pré-seleção dos dados e posteriormente as cenas foram adquiridas para uma investigação mais aprofundada. Criou-se uma chave de interpretação para as condições de nuvens da área de estudo e foram agrupadas cada uma das 125 cenas em uma Análise de Componentes Principais (ACP). A ACP agrupou meses com similaridades nas condições de nuvens, destacando seus padrões em termos de estação chuvosa e seca para a área de estudo. Outro resultado interessante foi que, mesmo sob o regime adverso de nuvens inerente da Amazônia, o uso combinado de ambos dados de imagens de satélites gratuitos pode ser útil para uma análise mais aprofundada, como a mensuração de clorofila a, matéria orgânica colorida dissolvida, sólidos suspensos totais e turbidez. No entanto, destaca-se que, primeiramente, investimentos devem ser realizados de forma a validar dados in situ, para que um programa de monitoramento possa ser construído através de aplicações de sensoriamento remoto.

Palavras-chave: águas amazônicas, lago bolonha, sensoriamento remoto.

1. INTRODUCTION

Eutrophication is a process that causes water deterioration in lentic environments (Lobato *et al.*, 2015) and also affects the spatial distribution of aquatic macrophytes (Madgwick *et al.*, 2011; Søndergaard *et al.*, 2010). These water vegetation contributes to primary productivity, sediment accumulation, provision of food and complex habitat for aquatic and semi-aquatic biota (Poikane *et al.*, 2018). Furthermore, macrophytes act as integrators of environmental conditions to which they are exposed and thus can be used as long-term indicators for water-quality monitoring (Pall and Moser, 2009; Melzer, 1999).

Studies highlighted that current water-quality evaluation is limited due to three main factors: i) in-situ sampling and measurements of water-quality parameters are labour-intensive, time-consuming and expensive; ii) analysis of the spatial and temporal variations and water quality trends in large water bodies is almost impractical; and iii) the collected in-situ data is not 100% accurate considering the possibility of field-sampling or laboratory error (Gholizadeh *et al.*, 2016; Ritchie *et al.*, 2003).

In this context, remote sensing (RS) data and techniques offer a feasible means to explore spatial and temporal information, bringing a variety of insights related to tropical ecosystems (Martins *et al.*, 2018; Yang *et al.*, 2013). Among the RS possibilities for water quality monitoring, it is relevant to mention the use of open source data, such as Sentinel-2 Multispectral Instrument (S-2 MSI) and Landsat-8 Operational Land Imager (L-8 OLI) (Pahlevan *et al.*, 2017; 2019), which we used in the analysis of this paper.

As a risk for future works in monitoring the environment, the US government started the process of reviewing the data fees for Landsat family products (Popkin, 2018). This payment would be a step backward for Earth observation, since more than 100,000 papers have been produced since 2008, when the Landsat products started to be freely available. Stone (2010) reinforces the importance of the free distribution of satellite data, once it has applicability in a vast range of public and private sectors of society.

S-2 MSI is composed of two individual satellites, 2A and 2B; the first one was launched in June 2015 and the second one in March 2017. They have thirteen spectral bands, four at 10 m, six at 20 m and three at 60 m of spatial resolution. L-8 OLI was launched in February 2013. The satellite has nine spectral bands; except for the panchromatic (15 m), all the other bands work at 30 m of spatial resolution. The synergetic use of S-2 MSI and L-8 OLI for monitoring provides a temporal resolution of 2.9 days (Li and Roy, 2017) and, after using image fusion techniques, a spatial resolution of 10 meters, is possible and usable for both images datasets aforementioned (Beltrão and Teodoro, 2018).

Applications with time series of Landsat products are a possibility for mapping and behaviour analysis of small water bodies in the Amazon (Arvor *et al.*, 2018). Landsat historical series also offers the opportunity to analyse the ecological regime of floating macrophyte greenness throughout vegetation indexes (Terborgh *et al.*, 2018). However, in the Amazon, the seasonal variability of the main atmospheric constituents represents a challenge for optical RS (e.g., cloudiness regime, the high aerosol burden in the dry season, among others) (Martins *et al.*, 2018).

From this perspective, we aimed to analyse the combined use of S-2 MSI and L-8 OLI data in the Brazilian Amazon, considering a eutrophic aquatic environment under adverse conditions of clouds. Our study also aimed to build knowledge related to the possibilities of monitoring aquatic ecosystems in the region.

2. MATERIAL AND METHODS

2.1. Study Area

The Bolonha and Água Preta Lakes supply nearly 63% of the drinking water of the Metropolitan Region of Belém (MRB) (Pará, 2013). Both lakes are refuelled by the Guamá River waters (Bahia *et al.*, 2008). They are located inside the Utinga State Park-Conservation Unit (USPCU) and cover 17.29% of its total area (240.85 out of 1393.088 ha) (Pará, 2013).

One of the main objectives of the creation of the USPCU was to ensure the water potability for the population of MRB (Pará, 2013). However, the pollution of Bolonha Lake due to the immoderate discharge of wastewater is causing its eutrophication and the overgrowth of water macrophytes over its surface (Pará, 2013; Ribeiro, 1992). Figure 1, made in QGIS 2.18.17, shows the location of the Bolonha Lake, used as the object of study.

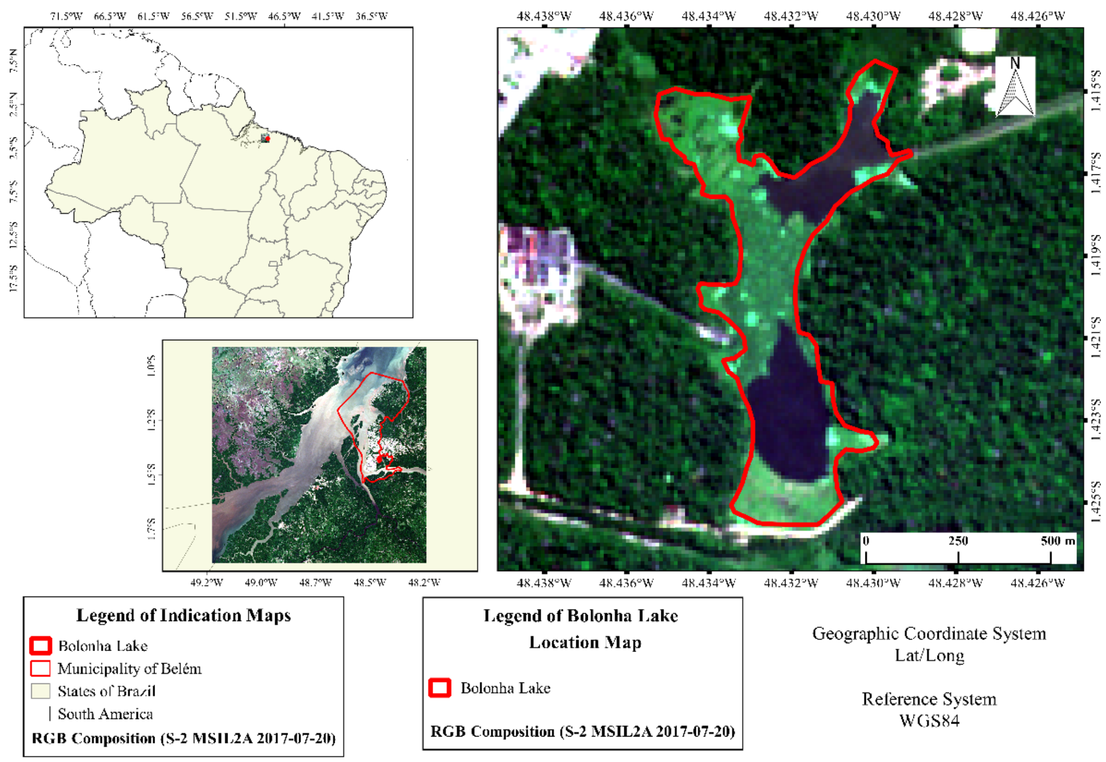


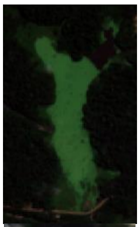
Figure 1. Location of the Bolonha Lake in Belém, Pará, Brazil.
Source: ESA (2018).

2.2. Image Selection and Key of Interpretation of the Cloud Conditions

We considered all available S-2 MSI and L-8 OLI images from July 2016 to July 2018. We acquired the selected images in August 2018 in the Copernicus Open Access Hub (for S-2

MSI) and the Earth Explorer of the United States Geological Survey (for L-8 OLI). After that, we classified the collected images for the Bolonha Lake in three different cloud conditions: i) lake without cloud cover; ii) lake under partial cloud cover; and iii) lake entirely covered by cloud (Table 1). The S-2 MSI's operations phase images were excluded because the atmospheric correction could not be applied to them; hence, they are not suitable for most of the RS applications.

Table 1. Key of Interpretation applied to the study area. The S-2's coloured compositions in the example column were standardised as RGB: B4, B3 and B2.

Condition	Characteristics/Description	Example
Lake without cloud cover	Cloud-free images of the surface of the lake, including water mass, macrophytes and surrounding primary vegetation (e.g., S2A 20180630)	
Lake under partial cloud cover	Images that showed the lake under adverse conditions, but with a clear distinction between macrophytes and water mass (e.g., S2A 20180725)	
Lake entirely covered by cloud	Images not suitable for optical use, due to cloud obstruction of water mass, macrophytes and surroundings of the lake (e.g., S2A 20180426)	

Source: ESA (2018).

This optical analysis was applied for all assessed images of the Bolonha Lake, scene by scene, and, even though there were scenes where the lake was under partial cloud cover, we distinguished which one of those scenes were optically useful for RS applications. The criterion we choose for this was the qualitative aspect of cloud fragments and shadows of cloud over the surface of the lake. With this criterion, we considered scenes as optically useful in situations where the cloud interferences could not affect the distinction of the water mass, the water vegetation and the primary vegetation around the Bolonha Lake.

We applied a quantitative approach, through PAST 3 software, to the filtered data using Principal Components Analysis (PCA) (Finkler *et al.*, 2015; Venkata Krishnamoorthy and Reddy, 2019) for the useful images of the Bolonha Lake. In this analysis, we considered the groups of images classified as "lake without cloud cover" and "lake under partial cloud cover" that surpassed the criterion from the cloud interference as useful data; the remaining scenes summed up to not suitable scene data.

3. RESULTS AND DISCUSSION

3.1. Data Classification and Characterization

In the Bolonha Lake region, most of the S-2A MSI scenes were found in operational phase until June 2016, which left us the option to analyse only the subsequent scenes – in such a way that the combination of proper S-2 MSI and L-8 OLI images were considered. After the launch and operational phase of S-2B, the number of scenes to be investigated increased considerably.

We found 125 scenes for the study area within the satellite imagery data in the period assessed, from which 77 scenes were from the S-2 MSI satellite, with an annual distribution as follows: 11 from July to December 2016, 27 from January to December 2017 and 39 from January to July 2018. For the L-8 OLI satellite, we found 48 scenes, distributed as follows: 12 from July to December 2016, 23 from January to December 2017 and 13 from January to July 2018. The S-2 MSI and L-8 OLI scenes of the Bolonha Lake were classified and quantified in terms of their suitability for RS applications, as shown in Figure 2.

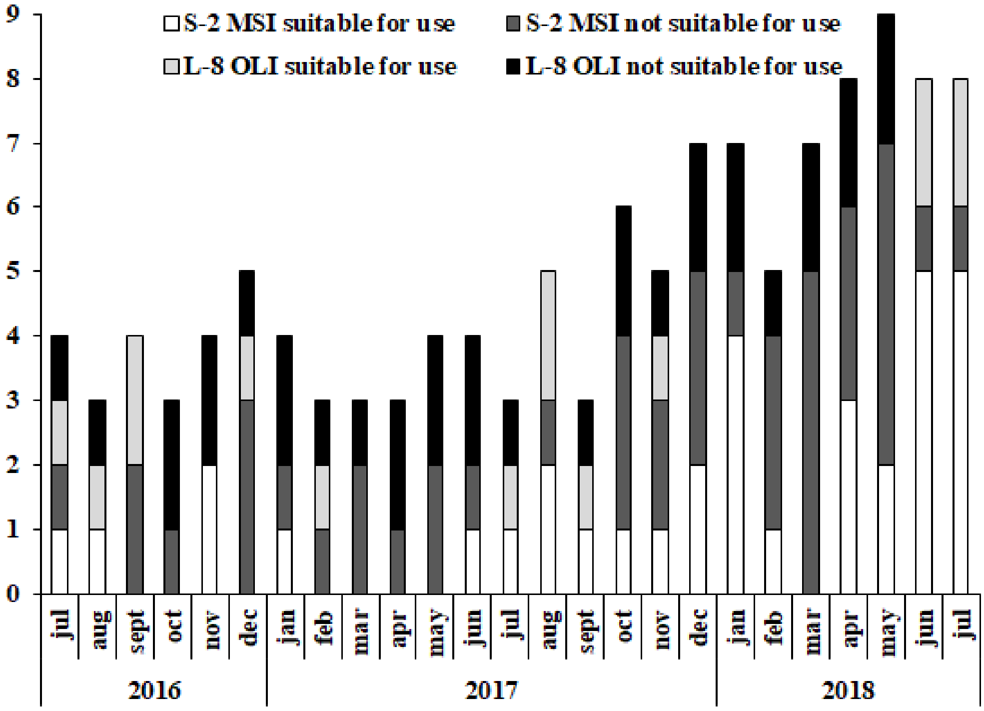


Figure 2. Classification of the suitability of S-2 MSI and L-8 OLI scenes for RS applications in terms of the cloud condition for all available data of the Bolonha Lake, from July 2016 to July 2018.

Due to its shorter revisit time (5 days) (ESA, 2015), S-2 MSI presented more available data than L-8 OLI (16 days) (USGS, 2016). The different sensing periods for the same area assisted in the selection of the optically useful images, improving temporal resolution for monitoring, agreeing with what is argued by Li and Roy (2017), e.g., in August 2017 there were four cloud-free images of the Bolonha Lake, being two of each satellite.

The gap of optically useful scenes between the months of March and May 2017 occurred because the S-2B satellite was still under the pre-launch phase (ESA, 2015). Furthermore, the L-8 OLI in the same period provided four scenes of the lake entirely covered by cloud and one scene where the Bolonha Lake was under partial cloud coverage – but with almost all pixels over the lake obstructed by clouds – i.e., those data were not suitable for RS applications.

The optical analysis and application of the key of interpretation resulted in 49 scenes of the study area suitable for RS applications, of which 34 were from S-2 MSI and 15 from L-8 OLI. We found around one useful scene per month of the Bolonha Lake (October 2016, March, April and May 2017 and March 2018 were the only months with no usable image found). This implies that the monitoring of aquatic environments using S-2 MSI and L-8 OLI imagery data is feasible even under the inherent excessive cloud regime of the Amazon (Martins *et al.*, 2018).

The results of the PCA of the first (78.6%) and second (21.4%) components, suitable S-2 MSI and L-8 OLI data and total satellite available data, respectively, pointed out three different groups (Figure 3). The similarities were found as follows: i) July to November 2016, January to July 2017 and September 2017 (red); ii) December 2016, October to December 2017 and February to May 2018 (green); and iii) August 2017, January 2018 and June, July 2018 (blue).

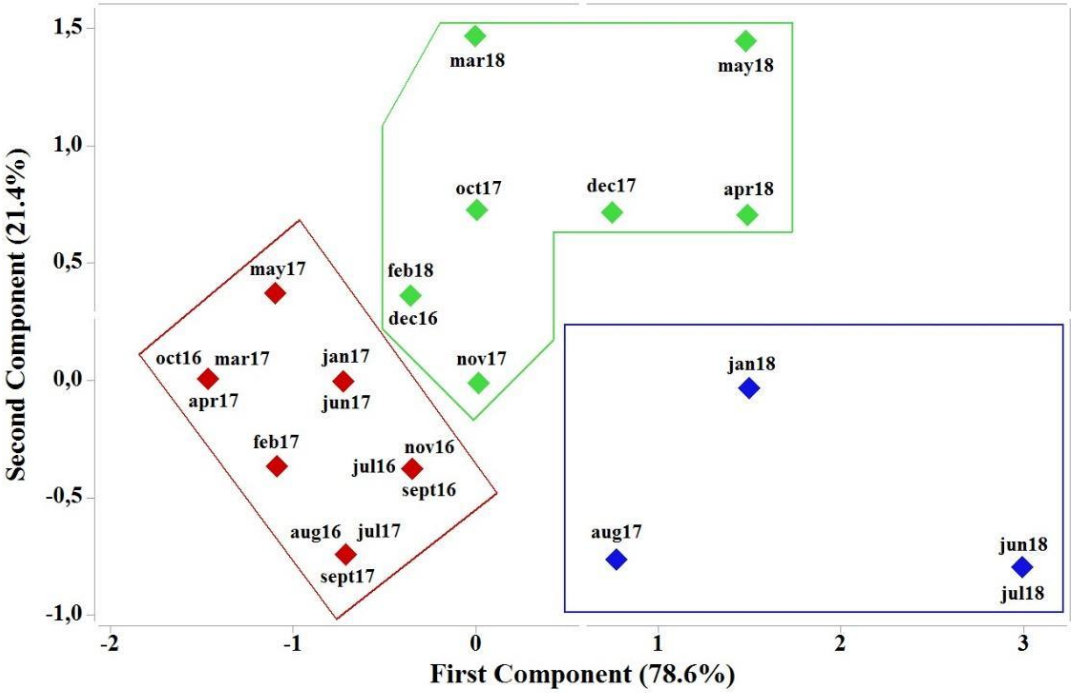


Figure 3. PCA illustrating the groups of similar months with overall cloud condition and useful S-2 MSI and L-8 OLI data for the Bolonha Lake.

The red group were assigned together due to the low availability and suitability of satellite data in these months. Prior to September 2017 (Figure 2), the S-2A was operating alone and giving a few imagery data of the study area. The temporal resolution of L-8 OLI could only delivery two scenes per month. Added to those factors, we highlight that the rainy season of USPCU occurs during December until May (INMET, 2019), which corroborates the fact that during this period the images are found covered by cloud more frequently.

The similarity of the green group, except for December 2016, was due to the launch of S-2B satellite, which increased the temporal resolution over Bolonha Lake. This group presented more suitable optical data than the red group, even during the rainy season.

Lastly, the blue group, except for January 2018, was under the dry season in the USPCU area, i.e., the formation and density of clouds over the study area was much smaller than in the rainy season. This characterised a period with high availability of satellite data, in which almost all of them are suitable for optical RS applications; e.g., June and July 2018 both presented 16 available satellite data, from them, 14 scenes were optically useful for analysis of water parameters and its surface macrophytes of the Bolonha Lake.

There are few studies that attempted to demonstrate the suitability of combined S-2 MSI and L-8 OLI imagery (Pahlevan *et al.*, 2019). Furthermore, investigations of cloud patterns usually select bigger areas and use different satellite instruments, such as Moderate Resolution Imaging Spectroradiometer (MODIS) (Garcia-Carreras *et al.*, 2017).

Researches have highlighted different patterns of cloud cover over forested and deforested areas across distinct regions. Ray *et al.* (2003) studied the high occurrence of cumulus clouds over native vegetation areas in Southwest Australia. Teuling *et al.* (2017) analysed the substantial increase in cloud cover over large forest regions in Western Europe. Wang *et al.* (2009) investigated patterns of shallow cloudiness over deforested areas in Western Amazon. Durieux *et al.* (2003) found increased cloud cover over deforested regions due to the enhancement of seasonal contrasts in Eastern Amazon.

Considering the data from automatic weather stations in Eastern Amazon, Germano *et al.* (2017) analysed the breeze circulations inside USPCU between 2003 and 2012. The cloud-correlated data were precipitation, wind speed and direction. The results showed that the effects of the sea breezes on the precipitation were more evident in Belém and other farther inland cities, which experienced a high frequency of precipitation from 15:00 to 21:00 UTC. Therefore, we can infer that the satellite data for the study area were very likely to be covered by clouds, considering the start sensing period of both S-2 MSI (13:42 UTC) and L-8 OLI (13:22 UTC).

3.2. Optically Active Water Parameters

The goal of most aquatic RS is to extract the radiance of interest from all the other radiance components being recorded by the sensor system. To identify the organic and inorganic constituents in the water column (e.g., chlorophyll a or total suspended solids), it is necessary to isolate the subsurface volumetric radiance (L_v) from the total radiance (L_t) (Equation 1). This process usually involves careful radiometric correction of the remote sensor data to remove atmospheric attenuation (L_p), surface sun-glint and other surface reflection (L_s), the radiance that entered the water column but was scattered into the upper hemisphere before reaching the bottom (L_c) and bottom reflectance (L_b). However, it is only possible to isolate and calculate L_v within a region that is not cloud-shrouded (Legleiter and Roberts, 2005; Jensen, 2014).

$$L_v = L_t - \left(L_p + L_s + L_c + L_b\right) \quad (1)$$

RS data and techniques have been widely used to map the open water characteristics and their changes (Zhang *et al.*, 2018). Some of the water parameters optically active and the RS data used for these applications in the literature investigated are detailed in Table 2.

Table 2. Commonly measured and optically active water qualitative parameters using RS.

Water Quality Parameter	References	Satellite/Sensor Data Used
Chlorophyll a (mg L^{-1})	Novo *et al.* (2013) Watanabe *et al.* (2017)	L-5 TM [1] S-2 MSI, L-8 OLI
Coloured Dissolved Organic Matters (mg L^{-1})	Giardino *et al.* (2014) Ruescas *et al.* (2018)	MODIS, L-8 OLI, RapidEye S-2 MSI, S-3 OLCI [2]
Total Suspended Solids (mg L^{-1})	Umar *et al.* (2018) Pahlevan *et al.* (2019)	L-5 TM S-2 MSI, L-8 OLI
Turbidity (NTU)	Rudorff *et al.* (2018) Sakuno *et al.* (2018)	L-5 TM, L-8 OLI, MODIS S-2 MSI

[1]Landsat 5 Thematic Mapper; [2]Sentinel-3 Ocean and Land Colour Instrument.

Gholizadeh *et al.* (2016) described the satellites possibilities for monitoring of water parameters. For these authors, with the use of free Landsat data, it is possible to investigate the main water parameters that have optical responses. At the release date of their paper, the S-2 MSI was recently launched, so there was no trustworthy paper released yet, so the authors did not consider it in their article. However, in Table 2, we elucidate the possibilities of also using the S-2 MSI for the main water parameters estimation. The options of the identified optically active water parameters, together with the number of images available during the year, per month, opens the opportunity of spatio-temporal monitoring the Bolonha Lake with reduced cost and for constant periods, increasing the understanding of the dynamics of this water body.

4. FINAL CONSIDERATIONS

Our study analysed the optically useful RS data for the USPCU, considering the possibility of further analysis for the study area and its qualitative water parameters. We could conclude that the synergic use of S-2 MSI and L-8 OLI surpasses the cloud issue, granting almost a monthly optical useful image data for small areas, such as Bolonha Lake. However, joint efforts of the public actors interested in the area must be made to validate the data locally during the rainy and dry seasons.

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