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REGIONAL MANAGEMENT AND DEVELOPMENT WITH FREE MULTI-TEMPORAL IMAGES: THE CASE OF HYDROELECTRIC POWER INSPECTION

GESTÃO E DESENVOLVIMENTO REGIONAL COM IMAGENS GRATUITAS MULTITEMPORAIS: O CASO DA FISCALIZAÇÃO DE HIDRELÉTRICAS

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Abstract

The present research aims to analyze the case of the use of free satellite images in the inspection of works of hydroelectric plants and to propose its use in the management of regional development. The study performs a multitemporal analysis of CBERS-4 and Sentinel-2 data to assist the inspection process of the National Electric Energy Agency and proposes a reflection on this technology as a free tool for regional development management. The methodology observed inspection reports, images with different temporal and spatial resolutions and the ability of the images to integrate the inspection process of electricity generation in Brazil through photointerpretation. The results demonstrate that the processing of free images optimizes the human and financial resources, being able to verify three of the five stages of works supervised by the Agency to guarantee the schedule of implantation of the hydroelectric plants in any region of the country with the same capacity of use. In addition, remote sensing data are presented as an excellent tool in the management of regional development where the plants are implemented or other related management and monitoring applications, as they provide greater transparency and efficiency to the control over large areas, such as that exercised by the Agency, strengthening accountability and considerably reducing one of the most sensitive aspects to the regulatory body and the management of large areas: information asymmetry.

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Keywords: Inspection, Remote Sensing, Hydroelectric Plants, Accountability, Management.

Resumo

A presente pesquisa objetiva analisar o caso do uso de imagens de satélite gratuitas na fiscalização de obras de usinas hidrelétricas e propor sua utilização na gestão do desenvolvimento regional. O estudo realiza uma análise multitemporal de dados CBERS-4 e Sentinel-2 para auxiliar o processo de fiscalização da Agência Nacional de Energia Elétrica e propõe uma reflexão dessa tecnologia como ferramenta gratuita para gestão do desenvolvimento regional. A metodologia observou os relatórios de fiscalização, imagens com diferentes resoluções temporais e espaciais e a capacidade de as imagens integrarem o processo de fiscalização da geração de energia elétrica no Brasil por meio de fotointerpretação. Os resultados demonstram que o processamento de imagens gratuitas otimiza os recursos humanos e financeiros, sendo capaz de verificar três das cinco etapas de obras fiscalizadas pela Agência a fim de garantir o cronograma de implantação das usinas hidrelétricas em qualquer região do país com a mesma capacidade de utilização. Além disso, os dados de sensoriamento remoto se apresentam como excelente ferramenta na gestão do desenvolvimento regional onde as usinas são implantadas ou outras aplicações correlatas de gestão e acompanhamento, pois conferem maior transparência e eficiência ao controle sobre grandes áreas, como aquele exercido pela Agência, fortalecendo a accountability e reduzindo consideravelmente um dos aspectos mais sensíveis ao ente regulador e à gestão de grandes áreas: a assimetria de informações.

Palavras-chave: Fiscalização, Sensoriamento Remoto, Hidrelétricas, Accountability, Gestão.

Introduction

The National Electric Energy Agency (ANEEL) has the mission to regulate and supervise the generation, transmission, distribution, and sale of electric energy in Brazil under Law No. 9,427 / 96, which creates the Agency as an autarchy under a special regime. Brazil has 9,022 electric power generation projects in operation, totaling 175 GW of installed power. The distribution of the energy matrix has 60% of hydroelectricity, more than 25% of thermal source, and 9.46% of wind source. The perspective is an increase of approximately 37 GW, coming from 251 projects under construction and 687 with works not started (ANEEL, 2020). Table 1 lists ANEEL's inspection processes.

Table 1: Energy generation projects inspected by ANEEL. CGH- Hydroelectric Power Plant; EOL- Wind Power Plant; PCH- Small Hydroelectric Power Plant; UFV- Photovoltaic Solar Power Station; UHE- Hydroelectric Power Plant; UTE- Thermoelectric power Plant; e UTN- Thermonuclear power Plant

Power plants under construction				Power plants with construction not started		
Type	Quantity	power granted (kW)	%	Quantity	Power granted (kW)	%
CGH	4	7.112	0,07	3	7.100	0,03
EOL	131	3.995.295	36,91	215	8.072.270	30,51
PCH	28	366.710	3,39	94	1.316.512	4,98
UFV	25	834.852	7,71	331	13.262.853	50,13
UHE	1	141.900	1,31	2	212.000	0,8
UTE	61	4.129.867	38,15	42	3.584.026	13,55
UTN	1	1.350.000	12,47	0	0	0
Total	251	10.825.736	100	687	14.798.535	100

Source: ANEEL, 2020.

The inspection of generating plants by ANEEL aims to verify the execution of the project according to the previously approved schedule to ensure that the plant goes into commercial operation on the scheduled date. Historically, the engineering project monitoring used only information sent by the generation agents and on-site inspections by the assessment team. In this model, there was considerable scope for information asymmetry due to the difficulty of obtaining information on the spot, weakening the inspection process in the control, accountability, and transparency (MORAIS; TEIXEIRA, 2016). Although ANEEL has the support of State Agencies with agreements, it has reduced staff for the various legal attributions requiring bidding since 2010 (Table 2). The lack of ANEEL employees is common in all governmental spheres, especially for inspection in areas far from the urban region (ABREU, 2019; FERREIRA, 2013; MORAIS; SILVA; COSTA, 2008). Therefore, the increase in infrastructure works combined with the high degree of irregularities makes technological improvement crucial for a continuous inspection of public works in progress or under concession (MIRANDA; MATOS, 2015; VITAL et al., 2015). Technological innovation in the public sector is the instrument to achieve efficiency and agility in the face of growing demands in management and regional development (CHEN et al., 2009; COSTA; AZEREDO, 2005). Furthermore, innovations in the management and inspection process must include a territorial approach to development (GUMIERO et al., 2022).

Table 2: Number of ANEEL Servers (Apr / 2020)

Functional position	Law 10.871/2004	Filled positions	Deficit (%)
Regulation Specialist	365	311	-14.79%
Administrative Analyst	200	155	-22.50%
Administrative Technician	200	115	-42.50%
Total	765	581	-24.05%

Source: Goes, 2022.

In this sense, remote sensing has wide area coverage and periodic revisits over the same areas, which allows to monitor environmental changes with less human, material, and financial resources (CARVALHO; GOMES; GUIMARAES, 2016). Many studies use orbital images to monitor environmental infractions such as oil spills (e.g., DE MOURA et al., 2022; JAFARZADEH et al., 2021), deforestation (e.g., ALVES, 2002; DE BEM et al., 2020a), illegal use of areas protected by law (e.g., CABRAL et al. 2018; DE OLIVEIRA et al., 2017), forest fires (e.g., DE BEM et al., 2020b, SANTANA et al., 2018), invasion of public areas (e.g., de Carvalho, 2021), among others.

In the energy sector, remote sensing data have been used in various activities such as thermal monitoring of nuclear power plants (BONANSEA et al., 2021; MA et al., 2017), detection of potential areas for the implementation of solar power plants and wind farms (WANG et al., 2016; SPYRIDONIDOU et al., 2021), mapping of solar plants (COSTA et al. 2021; PLAKMAN; ROSIER; VAN VLIET, 2022), maintenance of power lines (DENG et al., 2014; MATIKAINEN et al., 2016), and environmental changes from hydroelectric dams (BAUNI et al., 2015; JIANG et al. 2018; MANYARI; DE CARVALHO JR, 2007). Despite the various energy studies using satellite images, this tool in monitoring the construction phases of hydroelectric plants is still unexplored. The studies focus more on the hydrological dynamics, sediment depositions, and environmental impacts in the reservoirs and rivers associated with hydroelectric dams (LIN; QI, 2019; DARAMA et al., 2019). Therefore, besides to inspection, the images provide data on the surroundings of the plants and lakes, assisting in government actions, territory management and understanding of regional dynamics (UGEDA, 2020; SILVEIRA et al., 2022).

The present research aims to evaluate the efficiency of free satellite images in the inspection of stages in the development of hydropower plant project, improving the management control in the public administration and strengthening the accountability of the inspection process. The research compares information from free satellite images and the milestones of the plant's implementation schedules inspected by ANELL in different locations in the Brazilian territory and verifies the applicability of multitemporal images as a territorial management tool, considering its potential and limitations.

Controls in public administration

As a corollary of the democratic State, Public Administration is subject to several controls (Di Pietro, 2014), seeking a balance between the effectiveness of Article 37 and the scope of Articles 70 to 74 of the Federal Constitution (1988). Thus, ANEEL exercises inspection control over the national infrastructure works in the electricity sector, mainly in the plants under implementation to supply the energy consumed throughout the country.

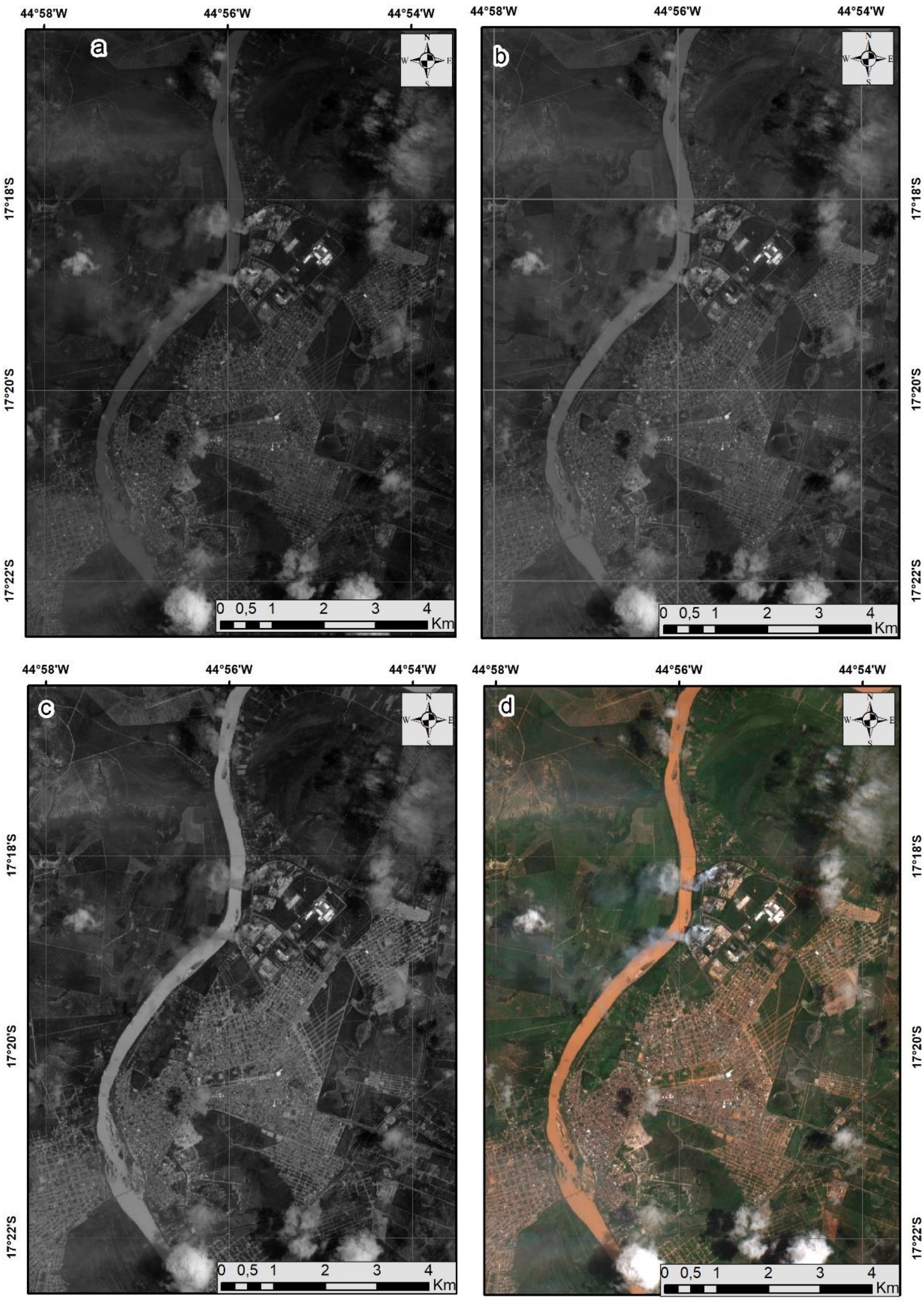
State control over major infrastructure constructions is essential to guarantee economic development, increase the population's income and employment (FILHO; TERRA, 2011). The improvement of the inspection and monitoring tools allows mitigating delays, financial deviations, and deficiencies in the inspection of large-scale engineering projects, such as hydroelectric plants (OLIVIERI, 2016; MIRANDA; DE MATOS, 2015). The scarce human and financial resources make technological innovation and the training of public servant basic needs in the current public administration (GOMES; MACHADO, 2018; PRZEYBILOVICZ; CUNHA; MEIRELLES, 2018; PORTO, 2017; STILLMAN, 2017).

Orbital images have several applications in different knowledge fields, such as cartography, military intelligence, meteorology, natural resource management, forest deforestation, and crop forecasts (Brazilian Space Agency-AEB, 2020). Orbital images are also suitable and efficient for inspecting public works (CARVALHO; GOMES; GUIMARAES, 2016). Continuous mapping and historical satellite data allow the temporal reconstruction of changes on the Earth's surface, such as the Landsat family, whose first was launched in the 1970s and is already in the nineth generation (Showstack, 2022). Multitemporal maps favor the planning and monitoring of regional development, including adding economic analyzes (CIMA et al., 2021).

Spectral, Spatial and Temporal Resolutions

In this topic, we present some basic concepts about satellite imagery. Spectral resolution involves the number of spectral bands that the sensor is capable of capturing. The subdivision of the electromagnetic spectrum in smaller intervals provides a greater number of bands and spectral resolution. A true-color image considers three bands in the spectral range of red, green, and blue (COELHO; BRITO, 2007) (Figure 1). In contrast, a panchromatic camera (PAN) covers a wide range of visible spectrum without discriminating colors, with images expressed in gray levels. The spatial resolution establishes the smallest observable element in a given image, establishing the ability to observe details in the images. For example, in an image with 0.50m of spatial resolution, it will be possible to see greater details than in the same image with 23.5m of resolution (Figure 2). Temporal resolution is the frequency of image acquisition from the same point on the Earth's surface (FÉLIZ; BACANI, 2018) (Figure 3).

Figure 1: Images of the Pirapora-MG (A) blue; (B) green; (C) red; and (D) Color Composition

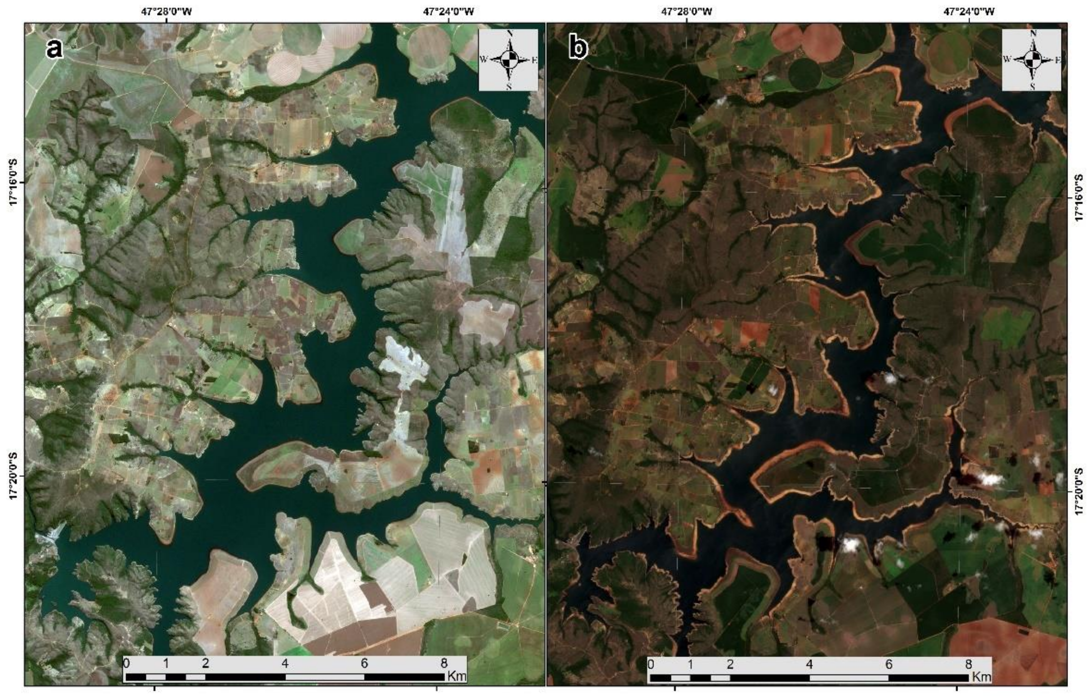


Source: Authors.

Figure 2: (A) Pleiades satellite (0.50m) and (B) Resourcesat satellite (23.5m).

Source: Authors.

Figure 3: Sentinel-2 images of the following dates: (a) 7/13/2020 and (b) 2/3/2021



Source: Authors.

Materials and Methods

The methodology was divided into three phases: (1) evaluation of ANEEL's external and internal reports, (2) selection of images with different temporal and spatial resolutions to detect the deployment phases according to the schedule agreed between the agent and the Agency (table 4), and (3) analysis of the capacity of remote sensing to integrate the Agency's inspection activities.

Aneel's Internal and External Reports

In this research, we used external information from reports and photographs on the construction monitoring sent by agents belonging to ANEEL and internal reports from the Agency. The monitoring routine of the generation plants involves analyzing the data sent by the agents about the fulfillment of the implementation schedule (Table 3), which are compared with the photographs and reports sent to prove compliance.

Table 3: Milestones used by ANEEL to monitor hydroelectric plants

Phases	Goal	description
1	Proof of start of civil works for structures	Beginning of the excavation of the region or beginning of the execution of the cofferdam for diversion of the river.
2	Start of Concreting of Powerhouse	Effective start of concreting the powerhouse.
3	Start of Assembly Electromechanical.	Beginning of the assembly of the suction tube and / or spiral box (when applied in terms of built-in equipment) and / or penstock (when applied).
4	Filling start of Reservoir	Alteration of the normal level of the river due to the influence of the dam.
5	Start of Works Transmission System	Beginning of the effective construction of the transmission line (base of the towers / poles) or substation.

Source: information obtained by the inspection sector of ANEEL.

Selection of Remote Sensing Images

The selection of images considered free data and with adequate temporal and spatial resolutions. The spatial resolution must be compatible with the size of the inspected object and with an adequate return period with the inspection dates. The images chosen were from the CBERS4 and Sentinel-2 sensors. The images of the Chinese-Brazilian satellite CBERS4, made available by the National Institute for Space Research (INPE), have a spatial resolution of five meters in the panchromatic image (facilitating visual interpretation) and a temporal resolution of 52 days (INPE, 2019). Table 4 lists the characteristics of the CBERS4 images.

Table 4: Technical Characteristics of the CBERS4 Satellite Cameras

Panchromatic (PAN) and Multispectral Camera	
Spectral Bands	B01: 0.51 – 0.85 µm B02: 0.52 – 0.59 µm B03: 0.63 – 0.69 µm B04: 0.77 – 0.89 µm
Swath Width	60 km
Spatial Resolution	5 m (B01) / 10 m (B02, B03, B04)

Source: INPE, 2019.

The Sentinel-2 images are made available by the European Space Agency (ESA) with a spatial resolution of 10.0 m and a temporal resolution of five days, increasing the number of images available with CBERS-4. In this work, we use the images with the colored composition to facilitate photointerpretation (Figure 1). Table 5 lists the characteristics of the Sentinel-2 images used in this study.

Tabela 5: Technical Characteristics of the MultiSpectral Instrument (Sentinel-2)

MultiSpectral Instrument (MSI) - Sentinel 2	
Central Wavelength	B02: 0.49 µm B03: 0.56 µm B04: 0.665µm B08: 0.842µm
Swath Width	290 km
Spatial Resolution	10 m (B02, B03, B04, B08)

Source: ESA, 2010.

Analysis of Remote Sensing Data in Aneel's Inspection Activities

Each phase of ANEEL's inspection (Table 3) presents its changes in the environment, establishing diagnostic characteristics in the remote sensing images. The selection of multitemporal images considers each phase of the schedule described in table 3. As practical examples, we present two hydroelectric plants: Sinop and Bandeirante. The Sinop HPP, located on the Teles Pires River, MT, has 401.88MW of installed capacity and a 342Km2 reservoir, with the potential to serve 1.6 million consumers. PCH Bandeirante, located on the Sucuriú-MS river, has 28.0MW of installed capacity and a 2.68 km2 reservoir, contributing to the decentralization of energy supply and mitigating the environmental impact of being a small hydroelectric enterprise.

Results

Figure 4 shows the CBERS-4 images in detecting the first construction phase (proof of the beginning of the civil works for the structures) of the Sinop-MT Hydroelectric Plant. The works start in 2015 (Figure 4a), but it is only in April 2017 that the construction of the cofferdam begins (Figure 4b), becoming notable five months later (Figure 4c).

Figure 4: Multitemporal images of the UHE-SINOP (MT): (A) 15/09/2015; (B) 09/04/2017; and (C) 12/09/2017

Source: Authors.

The second stage (start of the powerhouse concreting) was impossible to identify in the images since the powerhouses are commonly installations located next to the dam (at the foot of the dam) and in covered structures, making visualization with any remote sensing image unfeasible. The evaluation of the third landmark (start of electromechanical assembly) was also not detected because there were no external changes visible through satellite images, characterizing a second limitation of the information obtained through the orbital images. The fourth stage (early fill reservoir) detection is easy due to the rising water level of the dam. The Small Hydroelectric Power Station Bandeirante is an illustrative example, as it peculiarly has two reservoirs that enrich the visual analysis. Figure 5 shows a Sentinel-2 time series with reservoir filling, first the West dam and then the East dam.

Figure 5: Sentinel-2 images of the BANDEIRANTE (MS) PCH: (A) 21/01/2019; (B) 26/04/2019; (C) 10/07/2019; and (D) 30/07/2019

Source: Authors.

Figure 6 shows the images of the “start of the transmission system works” phase of the Sinop Hydroelectric Power Plant (UHE). Figure 6b shows the installation of the transmission towers towards the Plant. We chose to use CBERS4 images in this analysis because of the better spatial resolution (5-m resolution), which shows small aligned circles produced by the suppression of vegetation at the base of the towers.

The results demonstrate the ability of free satellite images to confirm three of the five inspection phases used by ANEEL to monitor the implementation of hydroelectric plants. The remote sensor data enables confirmation of the companies' information, mitigating the need for field visits. This potential is decisive for economy and efficiency since the visit of 2 inspectors in the field for two days costs approximately R $ 7,891.64 (Table 6). The hours spent on face-to-face inspection could be used in other functions, representing an opportunity in a shortage of employees. The face-to-face inspection to confirm a phase lasts an average of 16 hours, while the work supported by satellite images corresponds to 2 hours. Administrative costs for issuing tickets, paying for daily rates, and renting vehicles further increase these amounts. Besides, the images provide a holistic view of the region of the project, adding agility, reliability, and modernity to the inspection.

Figure 6: CBERS4 images of the UHE-SINOP (MT): (A) 06/01/2016; and (B) 12/12/2017

Source: Authors.

Table 6: Estimated costs of on-site inspection with 2 inspectors

medium values	2 days (16 work hours)
Hours value	R$1.363,64
hotel and transportation	R$439,00
airline tickets	R$700,00
opportunity cost (14 hours)	R$1.193,18
Total cost of 1 inspector	R$3.695,82
Total cost of 2 inspectors	R$7.391,64
car rental	R$500,00
Total Cost for 2-Day Inspection	R$7.891,64
Note: a) inspector's average monthly salary	R$15.000,00
b) hourly value of the inspector (22days/8 h)	R$85,23

Source: Authors.

Inspection by remote sensing can be carried out in isolated locations in the country with equal ease, accessible inputs, and periodicity, even without a plan that requires an inspection trip in the field since the plants usually stay in isolated locations. The applicability of this technology and its effective use can be free (like the satellite images shown here), using free software without the need for bids (BRUNO, 2017).

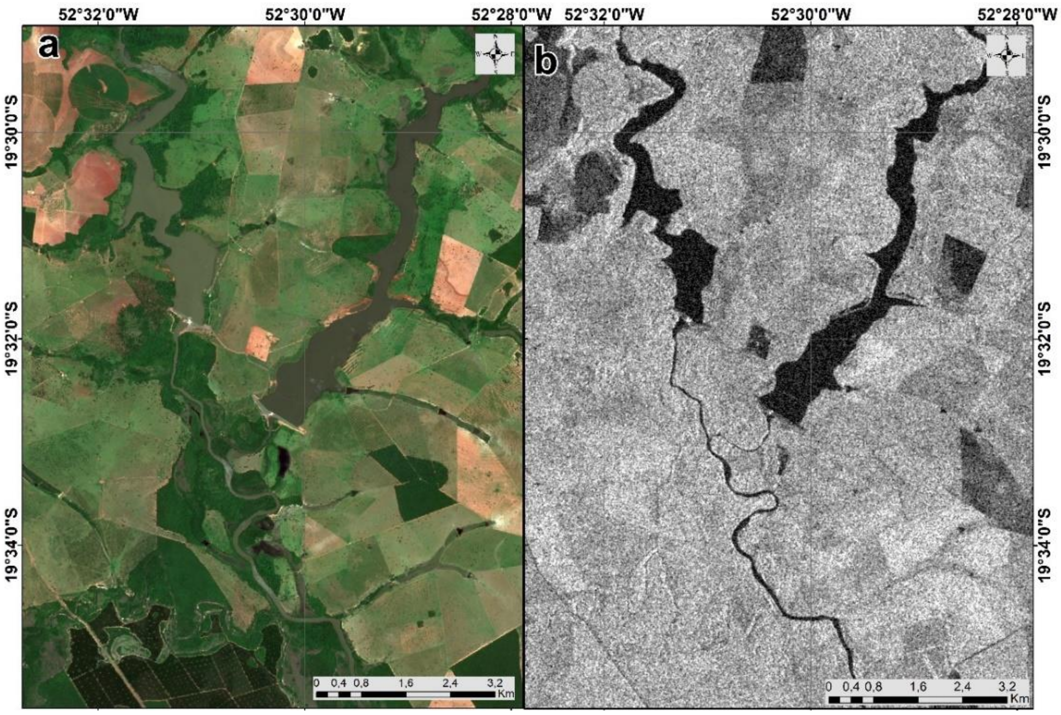
Concerning accountability, the acquisition of continuous images is a significant impediment for agents not to hide information or report facts that are not adherent to reality. This procedure reduces the information asymmetry between the regulator and the regulated agent, increasing the transparency and control exercised by the Agency, considering the public nature of the free images.

However, a limitation of optical images is the interference of cloud cover, shadows, and atmospheric effects (Figure 7). Some regions have long periods of cloud cover, such as the Amazon, which prevents the visualization of the Earth's surface on the monitoring dates. The alternative is to use radar images, which have wavelengths capable of crossing the clouds and reaching the Earth's surface, generating cloudless images. Figure 8 exemplifies the Sentinel-1 (Radar) and Sentinel-2 (optical) images.

Figure 7: Sentinel-2 images from UHE-SINOP (MT): (A) 05/27/2019; and (B) 4/21/2020

Source: Authors.

]**Figure** 8: BANDEIRANTE (MS) PCH: (a) Sentinel-2 (27/12/2019); e (b) Sentinel-1 (20/12/2019)



Source: Authors.

Discussion

The relationship between availability and energy consumption is closely related to regional development, having a high correlation with quality-of-life indicators (life expectancy, infant mortality, illiteracy, and birth rate) (GOLDEMBERG, 1998) and the Human Development Index (MARTINEZ; EBENHACK, 2008; YUMASHEV et al., 2022). Besides, the use of renewable energy sources (RE) is a critical factor in reducing greenhouse gas (GHG) emissions and promoting sustainable development (COOK; DAVÍÐSDÓTTIR; GUNNARSDÓTTIR, 2022). However, it is still a significant challenge for Brazil to expand renewable energy production to ensure industrialization and socioeconomic growth. In this context, the Brazilian energy system will increasingly depend on electricity to meet the demand for heat production and transport, requiring a doubling of energy demand by 2050 (GILS et al., 2017). Therefore, the existing hydroelectric plants added to the installations already under construction and coming from other renewable energy alternatives must be available in the future to guarantee a safe growth strategy.

This increase in plant construction (photovoltaic, wind, and hydroelectric plants) leads to an increase in the demand for inventories and inspections of the progress of the works throughout the Brazilian territory. The construction phase inspections have changed little over time, with the need for a professional to go to the site. To minimize field activities, a technological alternative would be the use of orbital remote sensing images that have been widely used for supervision in the environmental area with great success by the public sector (ALMEIDA et al., 2021, DE MORAES et al., 2016). The evolution of imaging systems provides data with free access and increasingly with better spatial, temporal, and spectral resolutions. For example, the latest version of CBERS (4A), released on December 20, 2019, provides free images with a 2-m spatial resolution and a 31-day temporal resolution (VRABEL, 2021). At the end of 2019, ANEEL developed an internal application that automatically provides free access to images of 3 satellite constellations for all areas of the Agency. Following global trends, the Agency seeks to develop as a next challenge the complete automation of analyzes through Artificial Intelligence in satellite images, replacing the photo interpretation made by inspectors.

The present research evaluated the sensors with free images, but other high-resolution satellite images for the commercial sale can be used containing a panchromatic band (from 1 meter to sub-metric resolutions) and multispectral bands (spectral bands of blue, green, red, and near-infrared with spatial resolutions ranging from 1 to 4 m). In the commercial field, the main sensors are: OrbView-3 (Panchromatic: 1 m; Multispectral: 4 m), IKONOS (Panchromatic 1 m; Multispectral: 4 m), QuickBird (Panchromatic: 0.6 m; Multispectral: 2.4 m), GeoEye -1 (Panchromatic: 0.41 m; Multispectral: 1.65 m), and Pleiades (Panchromatic: 0.5 m; Multispectral: 2 m), and WorldView-2 and WorldView-3 (Panchromatic: 0.3 m, 8 Multispectral bands: 24 m).

The analyzes carried out by the Federal Regulatory Agency reveal a potential for obtaining information with a reasonable level of detail. This situation demonstrates that more generic or detailed analyses can be performed with satellite images of specific spatial or temporal characteristics to meet the desired purposes. In this way, the images serve as a remarkable tool for managing large works, allowing their geolocated inventories and guidance for field work. In addition, satellite images are geospatial information rich in detail and easy to interpret, allowing various applications to support the management and monitoring of regions' development in the most distant parts of the country, which has a continental dimension. We can also highlight the potential to save financial and human resources in regional management, mitigating the shortage of employees in various entities that carry out management in the country.

Conclusion

The present research shows that free remote sensing images can help supervise works in public administration and optimize resources, constituting a simple, inexpensive, and effective tool for managing regional development. Such inputs bring efficiency and economic gains, constituting a simple tool to transform the State and optimize the investments already made by Brazil, such as the images from the Sino-Brazilian satellite CBERS. This possibility is viable both for federal agencies (such as ANEEL) and small municipalities due to the simplicity of analysis and availability of free software. Remote sensing images provide independent, objective, and reliable information that can be used for other inspection actions. Therefore, surveillance with satellite images plays an essential role in the democratic system, strengthening accountability and improving transparency in public management. In addition, the advent of other remote orbital sensors can support management and surveillance activity, increasing the free availability of orbital images with spatial resolution up to 2.0m. The present study demonstrates that the use of high-resolution images from the CBERS-4 satellite allows the detection of three of the five stages of the works of the hydroelectric plants supervised by the Agency. Therefore, the study demonstrates the feasibility of the tool in helping supervise the works of plants within a georeferenced context. In addition, the images contribute to the assessment of changes in the work's surroundings and its distribution in the country.

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