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Reuse of a dam as sediment trap and water reserve

Reutilização de barragem como armadilha de sedimento e reserva hídrica

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ABSTRACT

One of the dilemmas that characterizes the end of active service of small hydroelectric plants (SHPs) is regarding the destination of the dams. This is the case of the Pandeiros SHP, located in the state of Minas Gerais, Brazil. Several alternatives are being considered to make its decommissioning feasible, such as opening the bottom discharge gate and removing the reservoir containment dike. However, in a review of recent research in the basin, more than 200 active gullies were found upstream of the dam, contributing to the silting up of the reservoir and of the Pantanal Mineiro, an extensive wetland downstream of the SHP that is vital to the biodiversity of the region. Following a worldwide movement to reuse such structures, periodic dredging of part of the sediment retained in the reservoir is proposed, converting it into a trap to reduce the silting of the wetland by the upstream sediment, in addition to the creation of a reserve volume of water needed for agriculture and human consumption.

Keywords: Deactivation; Decommissioning; SHP; Drinking water supply.

RESUMO

Um dos dilemas que caracterizam o final do serviço ativo das pequenas centrais hidrelétricas (PCHs) é quanto ao destino das barragens. É o caso da PCH Pandeiros, localizada em Minas Gerais, Brasil. Diversas alternativas estão sendo consideradas para viabilizar seu descomissionamento, como a abertura da comporta de descarga de fundo e a remoção do dique de contenção do reservatório. No entanto, em revisão de pesquisas recentes na bacia, constatou-se a presença de mais de 200 voçorocas ativas a montante da barragem, contribuindo para o assoreamento do reservatório e do Pantanal Mineiro, um extenso pantanal a jusante da PCH que é vital para a biodiversidade da região. Seguindo um movimento mundial para reuso dessas estruturas, propõe-se a dragagem periódica de parte dos sedimentos retidos no reservatório, convertendo-o em armadilha para diminuir o assoreamento do pantanal por parte do sedimento de montante, bem como criar um volume de reservação para água necessária para agricultura e consumo humano.

Palavras-chave: Desativação; Descomissionamento; PCH; Abastecimento de água potável.

INTRODUCTION

Dam construction, be it for agriculture, cattle rearing, or human consumption purposes, or for flood control, leisure, or energy generation, has environmental and socioeconomic impacts that make it a venture that raises discussion and analysis among all stakeholders, especially those who will endure its impacts. There are several impacts resulting from the blockage and alteration of the natural flow of downstream water courses. This is because changes in the geomorphological characteristics of the normal river, the water, and its sediment transport and deposition processes affect the channel structure causing a disturbance in ecosystems, especially the ichthyofauna (Couto & Olden, 2018; Alla & Liu, 2021; Kondolf et al., 2014; Major et al., 2012; Schleiss et al., 2016; Pal, 2016; Tonkin et al., 2018; Zhang et al., 2022.

The response to such impacts was the adoption of proposals with maximal environmental appeal regarding the "return of rivers to their pristine state", these include the removal of the dam. According to Habel et al. (2020), this approach, which has been intensified since the 1980s, especially in the US, is based on the positive environmental impacts observed in several studies on the subject. Despite the sound results in terms of positive ecological effects from river flow restauration (Major et al., 2012; Pal, 2016; Wang et al., 2020), dam removal is neither a simple nor straightforward task (Habel et al., 2020; Perera & North, 2021).

One of the reasons is the uncertainty regarding the effectiveness of dam removal for subsequent ecosystem recovery, since this response is intricately linked to specific aspects of the physical and ecological environment, which are not always well known (Foley et al., 2017). As pointed out by Bellmore et al. (2019, p. 26) "despite the importance of the physical and ecological context of the specific dam and river" [..] "ecological responses to dam removal are generally governed by a shared set of physical and biological links and feedback loops". Therefore, for these authors (p. 36) is plausible that "the ecological communities that assemble following dam removal may be very different than (sic) those that existed before the dam was constructed".

The removal also involves procedures that require analysis of aspects such as of the biological and physical environment, the costs involved in structure demolition, and eventual landscape restoration costs. It must also consider safety and socioeconomic issues to provide a basis for decision making that envisages benefits both to the environment and the local communities, especially when the structure no longer generates energy (International Commission on Large Dams, 2018; Ministry of Natural Resources and Forestry, 2011).

No less relevant is the fact that the local population become used to the presence of the construction, having readapted their life routines and found ways to better take advantage of the structure, both for leisure and water supply. It provides local communities with a seemingly natural environment, albeit artificially created, which causes an additional hindrance to its removal. This increases the importance of the final decision and makes it even more complex (Habel et al., 2020).

However, as summarized by Serra & Oliveira (2020, p. 80), the main problem within the processes of landscape alteration due to the implementation of dam projects is that it happens […] "at a greater speed than the scientific capacity to comprehend the diversity, the processes and interactions that occur in biotic and abiotic […] environments". The same can be assumed as result of the removal, since it tends to affect the environmental conditions in a way that is not always fully understood (Bellmore et al., 2019; Foley et al., 2017).

Therefore, it is not surprising to find that currently, there is a certain convergence in various parts of the world on the need to seek alternatives to the removal of these structures as the only solution for river restauration (Bellmore et al., 2019; Couto & Olden, 2018; Alla & Liu, 2021). This is leading to the establishment of new approaches to dam decommissioning according to the characteristics of the project and its impacts. Such approaches seek to guarantee safety against ruptures, consider the environmental, socioeconomic, and cultural conditions of each affected area, and go beyond merely ecological approaches (International Commission on Large Dams, 2018; Habel et al., 2020; Major et al., 2017; Morley et al., 2020). One of the alternative approaches is based on the idea of "recycling and reuses" of the dams and their sediments (Bellmore et al., 2019; Couto & Olden, 2018; Habel et al., 2020; Alla & Liu, 2021), which broadens the possibilities for dealing with dam decommissioning (Faure et al., 2017; Major et al., 2017).

The discussion is not restricted to large enterprises but also affects small hydroelectric power plants – SHPs (Kibler, 2012). Opperman (2018), for instance, draws attention to the results of recent studies in several countries showing that SHPs have a greater impact per megawatt than large hydroelectric projects, indicating the importance of performing more encompassing environmental analyses in regard to this type of structure. According to the Agência Nacional de Energia Elétrica (National Electric Energy Agency) in Brazil (Brasil, 2020), SHPs are plants that use power and water pressure to generate energy in the 5,000 – 30,000 kW power range and have less than 13 km^2 in total reservoir area. In Brazil, unlike large plants that require strict environmental licensing procedures, SHPs are subject to legislation that requires only simplified procedures regarding environmental impact studies. These are almost always carried out at a local level, without considering the context of the entire watershed and the impacts of the construction of more than one structure along the water courses (Couto & Olden, 2018, p. 95).

The situation tends to be more critical in older SHPs, which were constructed prior to the adoption of regulations aiming to protect the environment by minimizing or mitigating the impacts arising from such structures. This is the case of the Pandeiros SHP and reservoir, located in the upper part of the lower Pandeiros River, close to the homonymous community. The Pandeiros SHP was built in 1957, as an initiative to bring economic, rural, and social development to the São Francisco River basin, an important basin for the Brazilian economy. With an installed capacity of 4.2 MW, it was operated by Centrais Elétricas de Minas Gerais (Minas Gerais Electrical Centers) (CEMIG), but became inoperative in 2008 (Fonseca et al., 2008), taking the reservoir to an advanced state of silting, which conditions the passage of a large part of the flows to a narrow, created channel. Currently, decommissioning studies are underway (Instituto Mineiro de Gestão das Águas, 2017) and opening the reservoir gates has been proposed to achieve the removal of the sediments deposited in the reservoir, prior to removal of the dam itself.

However, the sediments being generated are associated with erosion from gullying processes caused by land uses which favors transport and accumulation along the river system, with high impact on the entire Pandeiros fluvial system, especially on the wetland ecosystem of the Pantanal Mineiro. The Pantanal constitutes a unique hydrogeomorphological feature located in the lower course of the river and, besides being the only area with such characteristics in the state of Minas Gerais, it accounts for a large part of the ichthyofauna reproduction of the middle São Francisco River, the main river in southeast Brazil. In this sense, the dam has been doing a good job retaining the excess sediment load, preventing it from reaching the wetland. As such, dam removal without gully containment and mitigation may enhance silting impacts not yet foreseen.

The second aspect to be considered is the fact that the dam provides the community with water for its different uses. Due to the sharp contrast between wet and dry seasons typical of the Cerrado Biome, it is not uncommon for the communities in the basin to experience water shortage during the dry winter period from May to October. The water accumulated by the dam thus serves as a reserve, increasing the need to preserve it.

Therefore, considering these aspects as well as the natural physical environment context of the area, we propose reuse of the Pandeiros SHP dam as a sediment trap and water reserve. This proposal is based on the analysis and results of several parameters associated with the characteristics and dynamics of the Pandeiros River. These include qualitative and quantitative characterization of hydrological and sedimentological parameters, covered by direct hydrosedimentometrical measurements in the river over three consecutive full hydrological years from November 2016 to October 2019, emphasizing the transport of suspended and bed sediments (Bandeira et al., 2020b).

These studies were conducted in the period from 2016 to 2020 by researchers from CDTN – Centro de Desenvolvimento da Tecnologia Nuclear (Center for the Development of Nuclear Technology), IGC/UFMG – Instituto de Geociências da Universidade Federal de Minas Gerais (Geosciences Institute of the Federal University of Minas Gerais), and IFNMG – Instituto Federal do Norte de Minas Gerais (Federal Institute of the North of Minas Gerais), Januária campus, who reported to FAPEMIG - Fundação de Amparo à Pesquisa do Estado de Minas Gerais (Research Support Foundation of the State of Minas Gerais), the agency who funded the project.

These reports focus mainly on the diagnosis of intense erosion taking place on the slopes of the Pandeiros River basin, the source of huge amounts of sediment deposited in the wetland known as Pantanal Mineiro or Pantanal do Rio Pandeiros near the mouth of the Pandeiros river on the left bank of the middle São Francisco River (Augustin et al., 2020; Bandeira et al., 2018, 2020b; Chagas et al., 2021; Oliveira et al., 2017). The reports also addressed questions such as alternatives to the proposed decommissioning of the Pandeiros SHP, via simple removal of its dam, taking into account the broader environmental context of the Pandeiros River.

There is also a concern regarding the quality of the water dammed by the Pandeiros SHP, measured through the application of the WQI – Water Quality Index (Araújo, 2021). In addition, there are studies on the resuspending of sediments that may contribute to decision making regarding the future of the dam. Nicolodi et al. (2010), in their study on wave resuspending in Lake Guaíba, Rio Grande do Sul, Brazil, comment that it is only possible to address the quality of a water body in line with the use given to the soil within the hydrographic basin. However, Chagas et al. (2018) noticed physico-chemical changes in water quality after resuspending sediments due to a dredging project in the Fundão channel of Guanabara Bay, Rio de Janeiro, Brazil.

MATERIALS AND METHODS

The study area

The Pandeiros River basin is part of the Pandeiros Environmental Protection Area (APA Pandeiros), created by State Law nº 11,901 of September 1, 1995, whose main role is linked with the preservation of the Cerrado biome (Bethonico, 2009; Fonseca et al., 2008; Minas Gerais, 1995). It is located in the northwestern region of the state of Minas Gerais, Brazil, on the left bank of the middle course of the São Francisco River, of which the Pandeiros River is a direct tributary (Figure 1) (Bandeira et al., 2020a; Augustin et al., 2020). Its basin covers part of the municipalities of Cônego Marinho, Bonito de Minas, and Januária.

The basin has approximately 395,300 ha, of which about 2,000 to 5,000 ha is occupied by a wetland located in the most downstream portion of the basin known as Pantanal Mineiro or Pantanal do Rio Pandeiros, which is dependent on flooding during rainy seasons (Figure 2). It contains dozens of marginal lakes that become interconnected during the rainy season due to the rise in the water level of the São Francisco River, which promotes retention of the water of the Pandeiros River (Oliveira, 2021), partially invading it.

The wetland is an outstanding component of the Pandeiros River basin landscape. In addition to its tourist attractions, it hosts an important humid ecosystem, which includes several fish species that enter the wetland, turning it into a relevant spawning area and nursery, responsible for the sustainability of aquatic life in the São Francisco River with a significant impact on the local economy (Bandeira et al., 2018; Fonseca et al., 2008; Lima, 2019).

The basin developed over predominantly siliciclastic and carbonate sedimentary rocks of the Urucuia and Bambuí Groups, respectively. The first group is stratigraphically higher, occupying more than 70% of the basin. Most of these rocks are weathered, presenting detrital covers in which Quartzarenic and Litholic Neosols predominate (Augustin et al., 2020). Downstream of the basin, where river erosion has caused greater embedding, rocks from the Bambuí Group, mainly limestone formations, are exposed, evidencing the geomorphological reworking that took place in the lower course of the Pandeiros River (Augustin et al., 2020).

As proposed by the Instituto Mineiro de Gestão das Águas (Minas Gerais Water Management Institute) (Instituto Mineiro de Gestão das Águas, 2020), the classification of waters according

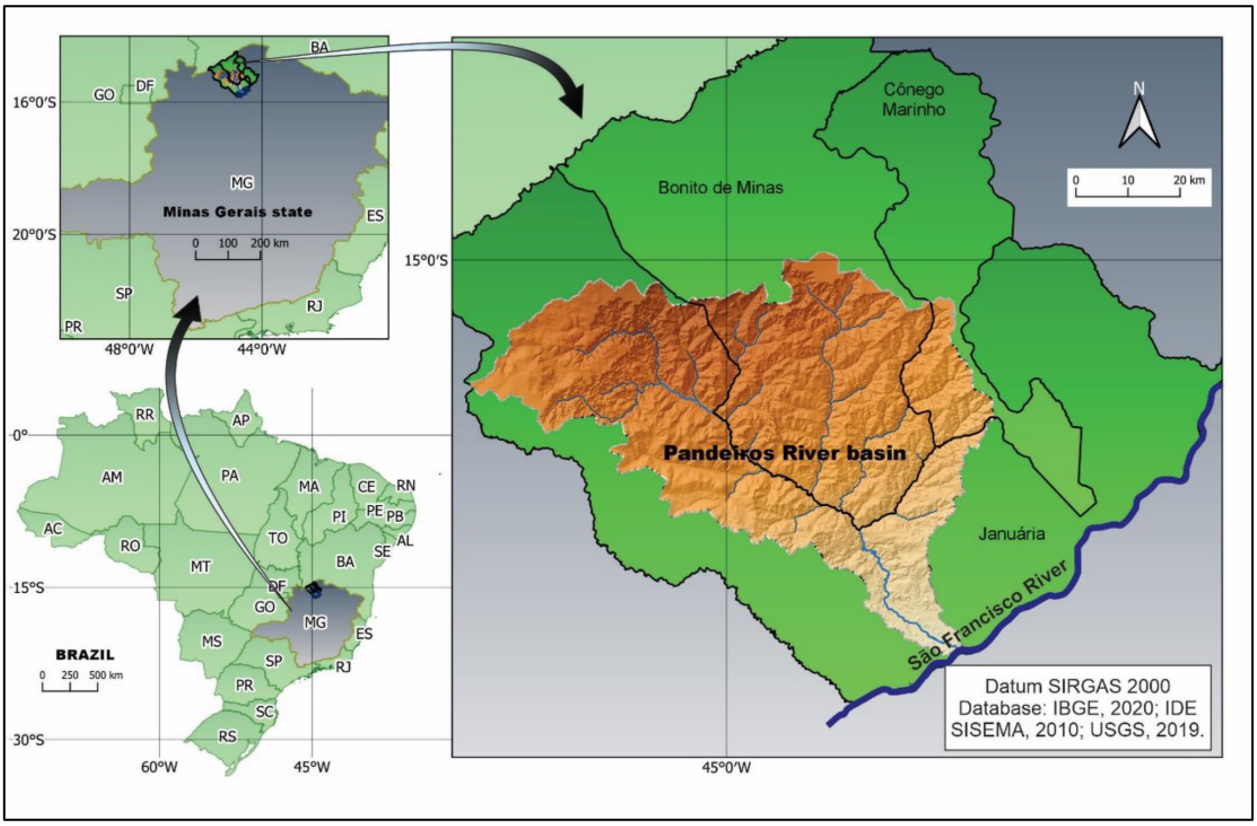

Figure 1. Geographic limits of the Pandeiros River Basin, Minas Gerais - MG.

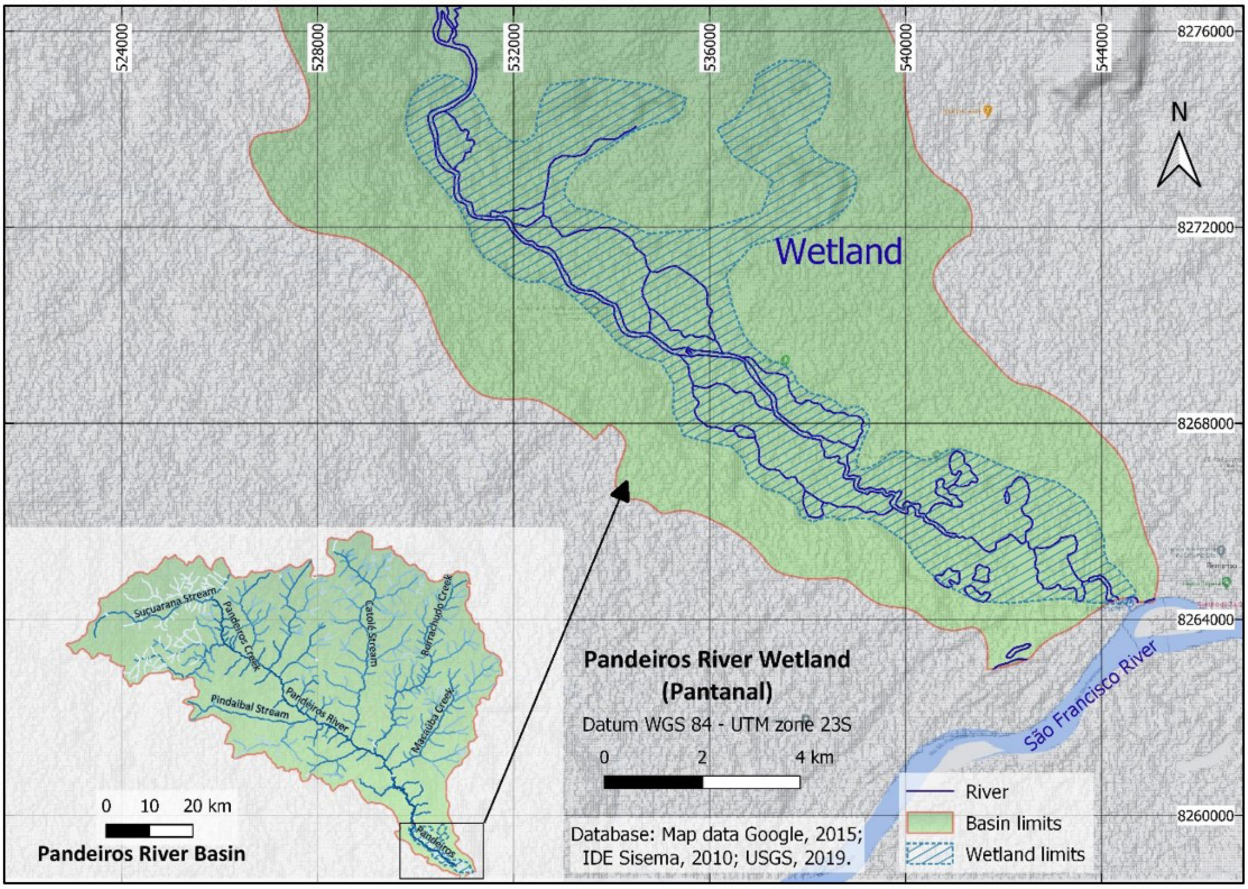

Figure 2. Location of the Pandeiros River Wetland (Pantanal).

to the WQI (Water Quality Index) is as follows: Excellent 90 < WQI ≤ 100; Good 70 < WQI ≤ 90; Medium 50 < WQI ≤ 70; Poor, 25 < WQI ≤ 50; and Very bad WQI ≤ 25

Regarding the water quality, Araújo (2021) obtained a WQI of 84.7 (qualified as Good) for the waters of the Pandeiros SHP reservoir. Also, according to the author, this WQI value indicates that after conventional treatment these waters can be used for public supply. Of the nine parameters evaluated in the waters of the SHP discharge channel, *Escherichia coli* (E. coli) concentration showed the worst quality result (qi), with 26.6 NMP/100 mL. Despite its low concentrations, the presence of this microorganism is an undeniable indication of wastewater discharge (both animal and human), given that E. coli is rarely found in water that has not received fecal contamination. According to Appendix I of Ordinance No. 291 (Brasil, 2011), water intended for human consumption must be free of E. coli. Therefore, the waters in the Pandeiros SHP and those directly downstream must undergo treatment before being consumed by the population.

Field sampling

To carry out the hydrosedimentometrical surveys in the Pandeiros River, data were measured at five stations: P1, P2, P3 (upstream of the Pandeiros SHP backwater area), P4, and P5 (at the beginning area of the Pandeiros wetland) (Figure 3).

It should be noted that the location of Station P3, known as the Pandeiros Montante Station, has been under the responsibility of the Agência Nacional de Águas (National Water Agency) (ANA) since 1973, being operated in conjunction with the Centro de Desenvolvimento da Tecnologia Nuclear (Center for the Development of Nuclear Tecnology) (CDTN) from 2016 to 2019. In addition, three rainfall stations near the Lavrado, São Domingos and Borrachudo streams (Figure 3) were also used. The quantification of total sediment transport in the channel was performed using the indirect method, sampling the water-sediment mixture in suspension via integrated sampling of the verticals in the cross section along with measurement of the dragged material using a sampler positioned directly on the channel bed (Carvalho, 2008; Carvalho et al., 2000). This indirect method, traditionally established in sedimentometric studies, is the methodology most often used in countries elsewhere in the world (American Society for Testing and Materials, 1997; International Atomic Energy Agency, 2005; Wren et al., 2000).

As shown in the literature, several agents promote rock weathering with the consequent formation of sediments, which can be moved and carried by surface rainwater runoff. Whether through dispersed or concentrated runoff, these sediments are

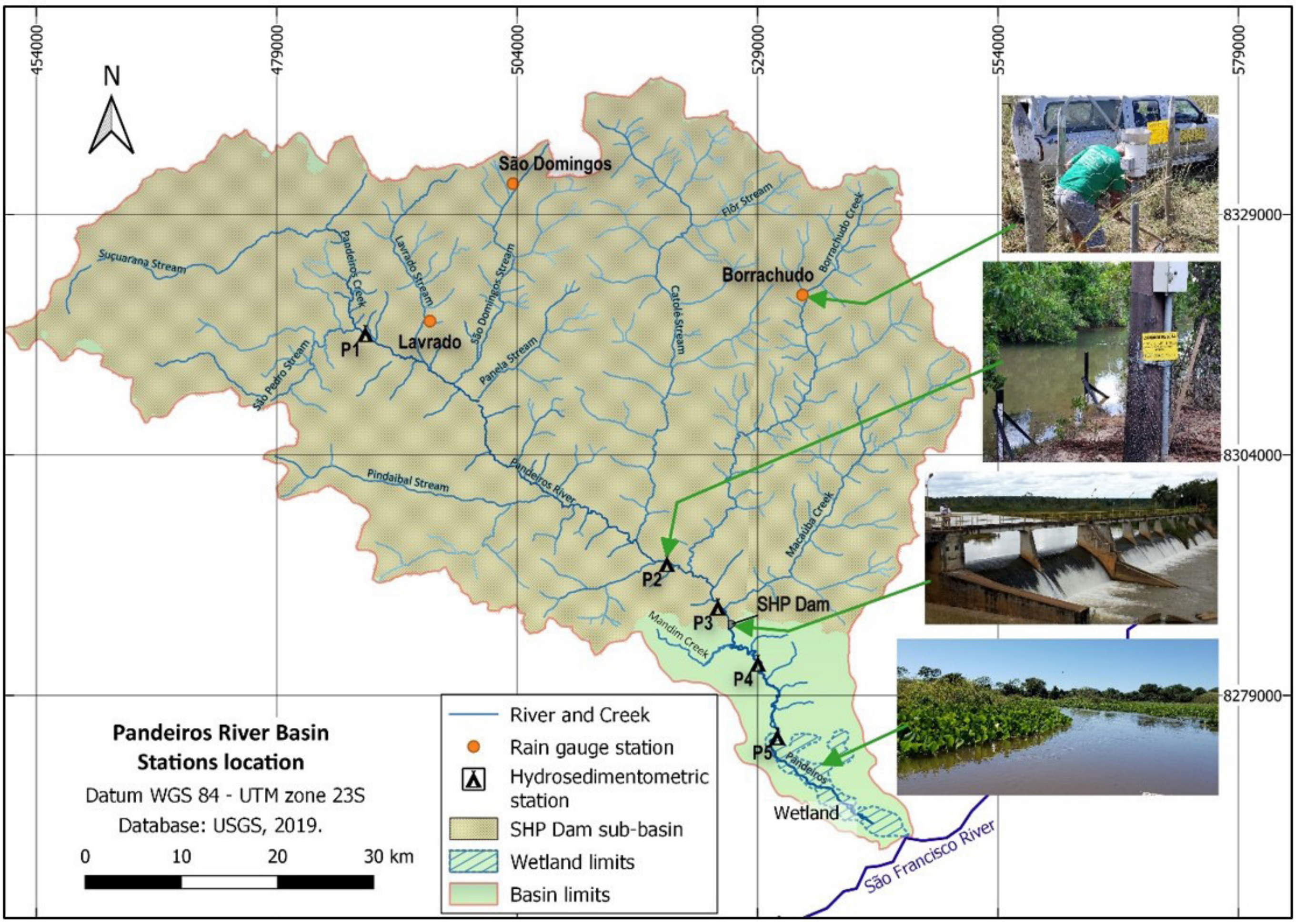

Figure 3. Location of the sampling stations for climatic and hydrosedimentometric measurements, Pandeiros River – MG.

eventually carried to riverbeds (Hack, 2020; Phillips et al., 2019). With this premise in mind, the qualitative and quantitative temporal survey of water and sedimentary transport in the Pandeiros River basin were based on field monitoring of precipitation, river water level, and surface runoff flow; laboratory measurements of the suspended and bed sediment load of the river, and the granulometric classification of the bed sediment load.

Between December 2016 and October 2019, hydrosedimentometric measurements were carried out, obtaining a total of 148 measurements from the five stations indicated in Figure 3, in addition to rainfall data. These campaigns were more frequent in December, January, and February, the months of highest rainfall. In the dry period, from April to October, a campaign was carried out every two months.

RESULTS AND COMMENTS

Sediment load

According to Cavalcante et al. (2021), the most impacting change in the entire river ecosystem is probably due to silting caused by the retention of sediments, especially those of medium to coarse granulometry affecting the entire fluvial environment both upstream and downstream.

The sediment load results for the Pandeiros River show a predominance of such granulometry. Note, in column D50 of Table 1, there is a predominance of medium sand along the river, except at Station P1, where the sand is fine. This is a typical grain size distribution for alluvial rivers (Carvalho, 2008).

Considering only the wet period from November to April, it was observed that the 2016-2017 biennium recorded the lowest mean monthly precipitation (98.8 mm), when compared to the precipitation observed in the 2017-2018 (189.7 mm) and 2018-2019 (130.2 mm) biennia, as shown in Table 2.

It can be observed that the accumulated precipitation in the hydrological year 2017-2018 (Figure 4) was the highest in the three-year period of the study, as recorded at the three rainfall stations installed in the basin. This directly interfered with the transport of sediments at each station, causing the highest loads to occur, when the mean accumulated precipitation of the rainfall stations was higher (1,220 mm).

The results of the sediment transport measurements reflect the expected contrast between the rainy and dry seasons, typical in areas of the Cerrado Biome, indicating, however, that the highest sediment load occurred in the hydrological year from November 2017 to October 2018 when compared to the other two hydrological years, November 2016 to October 2017, and November 2018 to October 2019.

The sediment load behavior is more understandable when comparing the three rainy seasons, from November to April of each hydrological year (Figure 5). It is noted that these quantities are interdependent, insofar as erosion resulting from natural and anthropic causes are concomitant along the watercourses, including tributaries.

The area contributing to the upstream flowrate at Station P1 has a maximum slope of 80 m.km^{-1} in the steep slopes stretch denominated Escarpment Domain by Oliveira et al. (2017), and thus presents a high potential for erosion processes on the slope and in the river channel. The presence of more than two hundred gullies upstream of this area (Lima, 2019) also accounted for the highest recorded sediment transport loads (Figures 4-5). Therefore, it is possible to assume that the area upstream of Station P1 is an important source of the sediment contribution.

As observed, a considerable portion of the sediment that passes through Station P1 settles in the meandering stretch of 60 km to Station P2, with an average slope of 1.15 m.km^{-1} (Bandeira et al., 2020b), lower than in the river region upstream of Station P1.

Table 1. Bed sediments granulometry.

Station	Median diameter			
	D35	D50	D65	D90
P1	0.11	0.16	0.22	0.38
P2	0.27	0.31	0.35	0.44
P3	0.25	0.30	0.34	0.44
P4	0.24	0.28	0.33	0.43
P5	0.26	0.30	0.34	0.45

Notes: median of the granulometries sampled during the field campaigns; D50 is the mean granulometry.

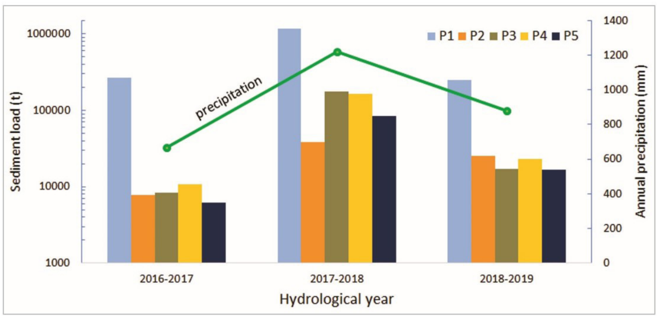

Figure 4. Total sediment transport at the hydrosedimentometric stations and accumulated annual precipitation. Pandeiros River – MG. Source: modified from Bandeira et al. (2020b).

Table 2. Mean monthly rainfall.

Hydrological year[a]	Rain gauge station						Mean	
	LAVRADO		SÃO DOMINGOS		BORRACHUDO			
	Wet[b]	Dry[c]	Wet	Dry	Wet	Dry	Wet	Dry
2016 - 2017	105.6	19.3	92.7	8.0	98.1	10.3	98.8	12.5
2017 - 2018	184.3	14.8	186.6	11.7	198.2	14.3	189.7	13.6
2018 - 2019	135.5	12.9	142.3	19.4	113.0	16.5	130.2	16.3

Source: Bandeira et al. (2020b). Notes: Mean monthly rainfall recorded by rain gauges during the hydrological year separated by rainy and dry seasons. [a]The local hydrological year is from November to October of the following year. [b]From November to April (wet season). [c]From May to October (dry season).

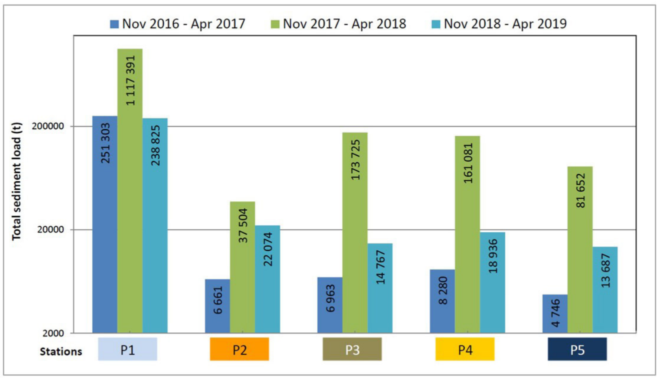

Figure 5. Comparison of the total sediment load during the 2016-2019 rainy seasons.

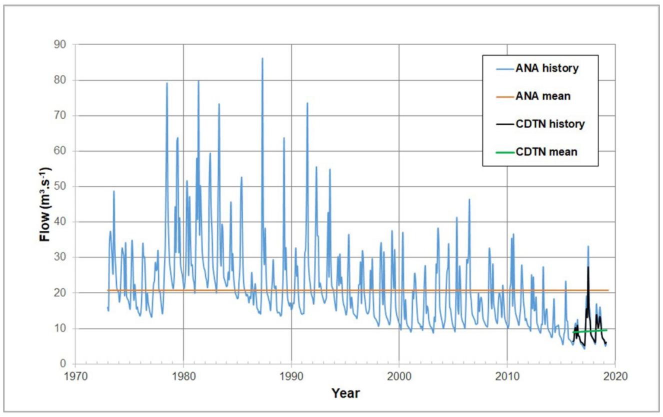

Figure 6. History of mean monthly flows measured by ANA (1973-2019) and CDTN (2016-2019) at Station P3. Pandeiros River. Source: modified from Bandeira et al. (2020b).

Stations P3 and P4 present similar behavior, whereby sediment load appears but a particularity must be discussed. Stations P1, P2 and P3 are located upstream of the Pandeiros SHP reservoir. This upstream area covers 3,634 km^2 and represents about 92% of the entire basin area (3,953 km^2), the reservoir being the only route for fluvial sediment transport (Figure 3). The SHP dam is located between Stations P3 and P4, which are 12.43 km apart. If it were not for the dam, the slope in this stretch would be 2.76 m.km^{-1}, which would considerably increase the sediment transport in this section (Bandeira et al., 2020b). Station P4 receives a large contribution of sediments from gullies located upstream of the Mandim tributary on the right bank and from the Campos community on the opposite bank (Chagas et al., 2021), so its sediment load is normally higher than that of P3 Station. The reduction in sediment load from P3 (173,725 t) to P4 (161,081 t) occurred only in the wettest season (Nov 2017 to Apr 2018) (Figure 5) and this was due to a greater spread of the river course to the flood plains of the SHP dam.

Due to the existence of the SHP dam, the sediments on the bed of the reservoir are mostly (95%) composed of sand with mean grainsize D50 = 0.3 mm. The fine sediments (Ø < 0.063 mm) transporting nutrients and organic matter are only partially retained in the reservoir, since it mostly remains in suspension and flows downstream (Bandeira et al., 2020b).

Station P5 is just upstream of the Pantanal do Rio Pandeiros and a systematic decrease in sediment transport from Station P4 to P5 can be observed, without exception, in Figure 5. The average slope (0.42 m.km^{-1}) is the lowest observed among the four stretches delimited by the five hydrosedimentometric stations (Bandeira et al., 2020b).

These results highlight the important role of the Pandeiros SHP dam as a tool in the retention of sandy sediments, thus contributing to a more expedient management of this watershed in the future.

Hydric reserve

The water scarcity in the basin is quite evident when comparing the data from the historical series of flows, made publicly available by ANA (National Water Agency) (Agência Nacional de Águas e Saneamento Básico, 2019), with the measurements taken during this study at Station P3, just upstream of the SHP dam (Figure 6).

The black line represents the measurements carried out by CDTN for water flows between September 2016 and December 2019, which is superimposed on the blue line, resulting from the ANA historical series.

Mean monthly flow was 20.8 m^3.s^{-1}, in the 45-year interval (1974 - 2019) during ANA's operation at the station. There is, however, a tendency of decrease in the mean monthly flows from the 1990s onwards. Thus, in the 2016 - 2019 interval, in which the CDTN carried out measurements at Station P3, the mean was 9.25 m^3.s^{-1}, that is, only 44.5% of the value corresponding to the historical period of station operation presented.

The analysis of the physical environment (Augustin et al., 2020; Bandeira et al., 2020a; França et al., 2018) shows that there was an adaptation of upstream drainage to a new base level established by readjustment to the different level created by sediments settling at the bottom of the dam. This has generated, among other effects, the reshaping of channels and changes in flow velocities upstream of the dam due to backwater, together with reduction of the sediment load downstream. Therefore, both the dam and the reservoir influence the natural conditions of liquid discharge, producing new stability conditions due to the relationship between the flow transport capacity and the sediment load released from the reservoir, promoting a new relationship between flow erosivity and margin erodibility (Cavalcante & Cunha, 2012).

In conclusion the results obtained thus far indicate: 1) a significant reduction in the average river level (height) upstream of the Pandeiros SHP in recent years (Bandeira et al., 2020b; Oliveira, 2021); 2) large amounts of sediments are produced by accelerated erosion processes, especially gullies (Augustin et al., 2020; Lima, 2019; Lima et al., 2019); 3) silting is a natural process inherent to reservoirs or lakes of hydroelectric plants (Carvalho et al., 2000); 4) high erosion rates on the steep slope and sandy soils in the tributaries generate plentiful silting in low-slope stretches downstream (Augustin et al., 2020; Bandeira et al., 2020a); and 5) the overall quality of the water is good, but in the reservoir where it is located, it needs to be treated for drinking purposes

(Araújo, 2021; Moreira et al., 2021) to qualify it as a water reserve, in addition to a natural sediment trap.

Comments and proposal for the reuse of the dam

Studies (Chagas et al., 2021; Oliveira, 2021) show that the level of silting in the SHP reservoir has increased over time. Although part of these sediments is currently retained and in a certain state of equilibrium provided by the vegetation that covers the silted areas, it is assumed that, if the bottom gate of the SHP dam is opened, the flow will cause severe erosion upstream. This is because the removal of the deterrent structure in an area that already has a natural slope break tends to significantly increase the flow energy line, boosting the transport of sediment downstream (Augustin et al., 2020; Bandeira et al., 2020b). As such, much of the sediment already stabilized in the reservoir, in addition to that which is seasonally added, will be transported downstream. In the worst-case scenario, with dam removal, the impact of sediment remobilization will increase and become permanent (Korpak & Lenar-Matyas, 2019), intensifying the silting up process in the Pantanal wetland of the Pandeiros River.

Considering the worldwide movement for the reuse of reservoirs and the materials contained therein (International Commission on Large Dams, 2018; Habel et al., 2020; Morley et al., 2020) and in view of what has been exposed above on the various environmental aspects, including the hydrogeomorphological and geomorphological aspects, and the socioeconomic and cultural aspects affecting the surrounding population, the conceivably favorable effects of removing the dam have not yet been definitively demonstrated. It is therefore suggested that the structure of the Pandeiros SHP dam should be maintained as it presently is. Upstream dredging of the SHP reservoir is also proposed as the only effective option for the urgent and immediate minimization of the sediment contribution to the Pantanal. Corrective measures must also be implemented to reduce slope erosion in the upstream area, which represents 92% of the basin's total drainage area.

It is noteworthy the need for dredging in the dry months to create the trap for sediment deposition, especially sand, whose transport is more intense in the rainy months. In view of the average sediment input measured at Station P3, just upstream of the SHP reservoir, a first experimental dredging of around 26,000 m^3 is recommended. The dredged sand could be used in civil construction, either to produce bricks, as indicated by Junakova & Junak (2017, 2019), or in other alternative uses of sand such as public works, as highlighted by Faure et al. (2017), Wu et al. (2019), and Pimiento et al. (2021). The present proposal, in addition to the temporary control of sediment transport and silting, meets social demands such as labor occupation and sustainability by recycling natural resources, thereby preventing the riverbeds and their banks from being turned over to meet the construction demands of the area.

It must also be considered that the temporal fluctuation of water resources in the region indicates a clear downward trend from the 1990s onwards (Bandeira et al., 2020b; Oliveira, 2021). The dredging procedure will, therefore, concomitantly create a reserve volume, able to function as a water storage space, supplying eventual demands from the Pandeiros community and serving to regulate the Pandeiros River flow during the dry season. Furthermore, it is important to note that the waters of the reservoir present a "good" WQI grade and thus, pending conventional treatment, can be used for drinking (Araújo, 2021; Moreira et al., 2021). The current classification of the water in the reservoir could be the reference value for future monitoring.

CONCLUSION

It is to be expected that both hydroelectricity entrepreneurs and environmental authorities will seek solutions for the destination of dams following their demise. Decommissioning in large reservoir damming projects is already practiced in many countries under relevant legislation, considering all possible solutions to environmental issues such as the socio-economic, cultural, and safety impacts of the structure undergoing shutdown. The authors argue that similar procedures be adopted not only in the particular case of the Pandeiros SHP, but be extended to all small power plants, whose regulation is presently more flexible, in view of their impacts, as reported in recent literature.

In the case analyzed here, the importance of the structural integrity of the Pandeiros SHP is indicated as an essential factor for the preservation of ecosystems and human standards of living. Therefore, the pressure of sediments on the dam structure is an important safety item. What is proposed in relation to this issue is that the pressure can be relieved by dredging the sediment settled in the reservoir. This will enable the space created with sediment removal to act as a trap. At the same time, a study should be carried out on the influence of sediment resuspension on water quality, as well as on the definition of a place for the disposal of the dredged sediment and its use in civil construction activities.

All this effort must be accompanied by commitments to recover degraded areas upstream, preventing the sediment from reaching the Pantanal of the Pandeiros River, which is threatened with extinction.

Based on studies carried out in the basin by the CDTN, IGC-UFMG, and IFNMG research teams, there are strong indications that the mobilization of sediments due to bottom discharge ensuing with the opening of the Pandeiros SHP floodgate will affect not only the ichthyofauna and several other avian and terrestrial animal species that depend on of the Pantanal for their reproduction, but also the communities that depend on the volume of water currently retained by the dam. At the same time, the scenario of water scarcity in the medium and long term, indicated by the decreasing flowrate records of the Pandeiros River itself in recent decades, is remarkable enough to command urgent responses to preserve the environment.

In the social scenario, residents will be directly affected by the effects of alterations resulting from the actions to be taken. There is a deep-rooted feeling among many residents that the landscape that exists today is "natural" and that the reservoir created by the dam has always been there as part of their lives.

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