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Socio-environmental vulnerabilities associated with the implementation of highways on the banks of the public supply reservoir of the São Pedro Dam, Juiz de Fora, Minas Gerais

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Abstract

Introduction: One of the main forms of land settlement that generates serious impacts in water bodies is the construction of highways close to these systems.
Objective: To identify the socio-environmental impacts associated with two events: the widening of BR-040 (in 2007) and the construction of BR-440 (between 2010 and 2020), near the banks of São Pedro Dam reservoir, a public water supply source in Juiz de Fora, MG.
Methodology: A review of data from published papers, in which the area of study was the same and Water Quality Index (WQI) was used, was carried out in order to assess the water quality of this source, classified as a Class 1 water body. Data on water quality parameters provided by CESAMA were also analyzed. In addition, the progress of land development projects in the vicinity of the dam reservoir was regularly monitored from 2006 to 2017, allowing the gathering of information to be used in the analysis of associated consequences.
Results: The dataset showed that the aforementioned events caused severe damage at the socio-environmental level, such as suppression of riparian vegetation, silting of the water body, compaction and contamination of the soil, filling of springs with land, and diversion of its waters. As a consequence, WQI values in these periods were the worst, indicating poor water quality for supply purposes.
Conclusion: It is possible to double the volume of water treated by the local plant. This would reduce the risks of water shortage in the city during the dry season.

Keywords: Water quality. Water supply sources. Environmental impacts of highways. Land settlement. WQI index.

Vulnerabilidades socioambientais associadas à implantação de rodovias às margens do reservatório de abastecimento público da Represa de São Pedro, Juiz de Fora, Minas Gerais

Resumo

Introdução: Uma das principais formas de ocupação da terra, e que gera graves impactos aos corpos hídricos, é a implantação de rodovias próximas a esses sistemas.

Objetivo: Identificar os impactos socioambientais associados a dois eventos: obras de duplicação da BR-040 (em 2007) e de implantação da BR-440 (entre 2010 e 2020), às margens do manancial de abastecimento público da Represa de São Pedro, em Juiz de Fora (MG).
Metodologia: Foi realizada uma revisão de dados presentes em artigos científicos, da mesma área de estudo, os quais utilizaram o Índice de Conformidade ao Enquadramento (ICE), a fim de avaliar a qualidade da água desse manancial, enquadrado como classe 1. Foram realizadas ainda análises de dados de parâmetros de qualidade, disponibilizados pela CESAMA, e acompanhamentos periódicos, entre os anos de 2006 e 2017, da evolução desses empreendimentos às margens da represa, a partir dos quais foi possível levantar materiais para análises de consequências associadas.
Resultados: A partir dessa série de dados, observou-se que os eventos citados causaram diversos prejuízos ao meio socioambiental, como supressão de vegetação ciliar, assoreamento do corpo hídrico, compactação e contaminação do solo, aterramento de nascentes e desvio de suas águas. Como consequência, os ICE observados nesses períodos foram os piores, o que indica péssima qualidade da água para abastecimento.
Conclusão: Foi possível perceber a capacidade de aumento do volume de água tratado na ETA em até 2 vezes, o que diminuiria os riscos associados ao desabastecimento do município em épocas de seca.

Palavras-chave: Qualidade da água. Mananciais de abastecimento. Impactos ambientais de rodovias. Uso e ocupação da terra. Índice de Conformidade ao Enquadramento.

Vulnerabilidades socioambientales asociadas a la implementación de carreteras en los márgenes del embalse de abastecimiento público de la Represa São Pedro, Juiz de Fora, Minas Gerais

Resumen
Introducción: Una de las principales formas de ocupación del suelo, que genera graves impactos en los cuerpos de agua, es la implementación de carreteras cercanas a estos sistemas.
Objetivo: Identificar los impactos socioambientales asociados a dos eventos: las obras de duplicación de la BR-040 (en 2007) y la implementación de la BR-440 (entre 2010 y 2020), en los márgenes del manantial de abastecimiento público Presa de São Pedro, en Juiz de Fora (MG).
Metodología: Se realizó una revisión de datos en artículos científicos de la misma área de estudio que utilizaron el Índice de Conformidad al Cumplimiento (ICE), para evaluar la calidad del manantial, clasificado como cuerpo Clase 1. Fue realizado el análisis de datos de parámetros de calidad, proporcionados por CESAMA, y el seguimiento periódico, entre 2006 y 2017, de la evolución de los proyectos de barrios en las orillas de la presa. Así fue posible levantar materiales para el análisis de las consecuencias asociadas.
Resultados: Colectados los datos, se observó que los eventos citados ocasionaron diversos daños al medio socioambiental, como la supresión de la vegetación ribereña, la sedimentación del cuerpo de agua, la compactación y contaminación del suelo, el vertedero de manantiales y el desvío de sus aguas. Como consecuencia, los ICE observadas en estos períodos fueron los peores, indicando la pésima calidad del agua para abastecimiento.
Conclusión: Fue posible percibir la capacidad de incrementar el volumen de agua tratada en la ETA, hasta 2 veces, reduciendo los riesgos de escasez de agua en épocas de sequía.

Palabras clave: Calidad del agua. Fuentes de suministro. Impactos ambientales de las carreteras. Ocupación del suelo. Índice de Conformidad al Cumplimiento.

Introduction

Urban development processes result in conflicting actions: while such processes increase demand for high-quality water, they are notoriously linked to changes in soil and, consequently, to the degradation of water resources. Land use and settlement have direct effects on water availability dynamics, both quantitatively and qualitatively (PIAZZA *et al.*, 2017; DE SOUZA *et al.*, 2018).

This context highlights the importance of public water supply sources, especially

surface water sources such as reservoirs. Associated risks are highest in such systems, as they are more exposed to outside contamination and, therefore, prone to the spread of waterborne disease among the population (FAIAL, 2017; LEMOS & JUNIOR, 2019; CRUZ & MIERZWA, 2020).

The Brazilian Forest Code, Federal Law No. 12,651/2012, in its Article 5, seeks to protect human water supply sources and make them perennial—thus ensuring its long-term preservation—by defining Permanent Preservation Areas (PPAs), in rural areas, as strips of land at least 30 meters wide around public water supply reservoirs (BRASIL, 2012; MAGALHÃES & BARBOSA JUNIOR, 2019).

> Art. 5. In the implementation of artificial water reservoir intended for power generation or public supply, the acquisition, expropriation, or institution of administrative easement by the entrepreneur of the Permanent Preservation Areas created in its surroundings is mandatory, as established in the environmental licensing, observing the minimum range of 30 (thirty) meters and maximum of 100 (one hundred) meters in rural areas, and the minimum range of 15 (fifteen) meters and maximum of 30 (thirty) meters in urban areas. (BRASIL, 2012).

In these strips of land, preservation of existing vegetation—known as riparian forest—is mandatory. Riparian forest is a forest system that surrounds water bodies, and its main function is the conservation of said bodies. This vegetation cover protects the soil against erosion processes and resulting aggradation. Soil exposure is often accompanied by earthworks and waterproofing, which may lead to the carrying of various contaminants directly to bodies of water (CASTRO, CASTRO & DE SOUZA, 2013).

Riparian forests hence act as sturdy physical barriers to the pollutants that come with surface runoff, such as solids, nutrients, or heavy metals (CASTRO, CASTRO & DE SOUZA, 2013; ROCHA & COSTA, 2015), also acting as an air pollution filter.

The construction of highways next to these systems is one of many forms of land use and settlement, with numerous negative effects on the environment, even more so in water supply sources. Both the construction and the operation of new roads have a negative impact during both the construction and operation phases. During construction, there are changes to the surface, including riparian forest suppression and cut-and-fill operations. These actions increase the pace of erosion processes, the carrying of particles, and the aggradation of the body of water, affecting the quality as well as the quantity of available water. Moreover, there is noticeable interference in local fauna, including changes to the migratory movements of some animal species and damage to biodiversity as a result of forest fragmentation (REZENDE & ALVES COELHO, 2016).

During operation, other environmental problems may occur in addition to the effects of construction, such as roadkill, increase in the incidence of arson around the highway, and

accidents involving hazardous loads, that lead to the contamination of the water supply source (REZENDE & ALVES COELHO, 2016).

Environmental concerns linked to the construction of highways near water reservoirs were the motivation of this study, which seeks to analyze these issues and to raise awareness of the gravity of such constructions, so that society may take a more active stance against said projects in these areas.

To this end, São Pedro Dam reservoir, a public water supply source in the city of Juiz de Fora, Minas Gerais state, was chosen as the object of study. The dam's surroundings have seen the widening of BR-040 freeway, in 2007, and the construction of BR-440 highway, between 2010 and 2018 (ROCHA *et al*., 2018a). These road projects have aggravated the impact of an already existing, disorderly land use and settlement process that gave birth to several land development and planned neighborhood projects. Such an impact has direct negative implications to the water stored in the reservoir, affecting the population of Juiz de Fora.

Objectives

Given the hydrographic importance of São Pedro Dam reservoir to the city of Juiz de Fora as a public water supply source, this paper seeks to identify socio-environmental vulnerabilities caused by the widening of interstate BR-040 and the construction of BR-440, as well as already observed impacts resulting from the aforementioned activities.

The secondary objective is to provide society in general with evidence and information that the aforementioned road construction projects have a direct impact on the quality and the quantity of available water, which may lead to several issues, such as waterborne disease and water shortage.

Method

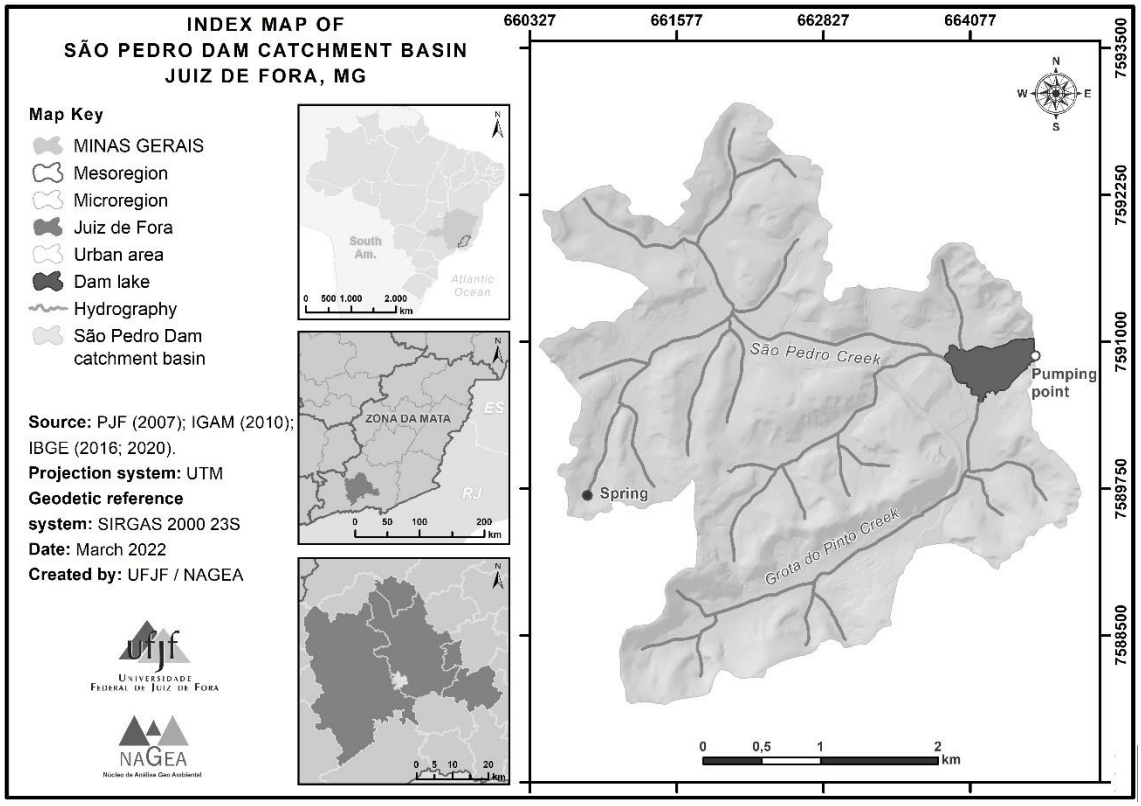
Methodologic procedures in this study consisted in the examination of related documents, papers, and legislation, as well as the analysis of secondary water quality data provided by the Municipal Sanitation Company of Juiz de Fora (CESAMA), which collects and analyzes water samples, on a monthly basis, from points situated downstream from where water is pumped out of the São Pedro Dam reservoir. Also, regular field trips were made to the premises, in order to closely monitor the progress of land development projects near the banks of the reservoir and to make photo reports to portray this progress over time.

Area of study

The São Pedro Dam reservoir, as shown in Figure 1, is located in the city of Juiz de Fora, in the region known as Zona da Mata, state of Minas Gerais. Its coordinates are 21°46'43.9" S and 43°24'29.2" W (datum: WGS 84). Total drainage area is approximately 13 km². Its main tributaries are São Pedro Creek and Grota do Pinto Creek. The region is a part of the Paraíba do Sul River basin. The local water treatment plant supplies about 8% of the city (ROCHA, SILVA & FREITAS, 2016; ROCHA *et al*., 2019a).

Figure 1

Index map of São Pedro Dam and its surroundings



Source: The authors (2022).

Despite its remarkable importance to the city, the dam basin has been subject to considerable human interference over time, owing to the lack of efficient public policy, causing severe degradation of water quality (RIBEIRO & PIZZO, 2011).

Water quality data

According to Minas Gerais State Council for Environmental Policy (COPAM) Normative Consideration No. 16/1996, that sets guidelines for classification of state waters in the

Paraibuna River basin (MINAS GERAIS, 1996), São Pedro Dam reservoir is a Class 1 body of water. Class 1 is reserved for the finest applications of human consumption.

As the water in question is used for public supply, water quality data provided by CESAMA in a 12-year span (2006–2017) was analyzed on a monthly basis. The data were set in an organized manner in spreadsheets and compared to information in published papers with the same area of study, for the purpose of making a review of existing literature. The authors of these papers used the Canadian Water Quality Index (WQI) as an indicator of water quality in the São Pedro drainage basin.

WQI is an index developed by the Canadian Council of Ministers of the Environment. It provides an efficient outlook of a given body of water's situation in terms of its classification (ROCHA *et al*., 2018a; ROCHA *et al*., 2019a).

The index is made of three elements: scope, which measures parameters that are not in conformity with established water quality standards; frequency, which indicates the number of instances of nonconformity between a parameter and its standards; and amplitude, which is simply the difference between the value of said parameter, as measured in the body of water, and the maximum limit required for the body of water's inclusion in a given class. It is therefore possible to adapt the Canadian index to Brazilian reality by allowing the inclusion of parameters better suited to each body of water. This makes it possible to assess if a given water supply source meets the criteria set in National Environment Council (CONAMA) Resolution No. 357/2005, that outlines water body classification and sets guidelines for class assignment (BRASIL, 2005; CCME, 2001a; CCME, 2001b; MMA, 2005; AMARO, 2009; ANA, 2012).

Calculation of WQI yields results that indicate whether a body of water does meet applicable criteria or not, determining conformity or nonconformity with established standards. The classification of this index encompasses five intervals (or classes): excellent (95–100), good (80–94), fair (65–79), marginal (45–64), and, lastly, poor (0–44) (AMARO, 2009; ANA, 2012).

In order to calculate WQI for the water in São Pedro Dam basin, the following parameters were considered in this study: pH, color, turbidity, iron, chlorides, hardness, dissolved oxygen, consumed oxygen, conductivity, $BOD_{5,20}$, total phosphate, total nitrogen, and *Escherichia coli*.

Monitoring the progress of development projects

The construction progress of the land development projects was monitored by a multidisciplinary team of academicians and technicians, namely civil engineers, environmental and sanitary engineers, production engineers, geographers, biologists, and firefighters—amongst other professionals—who took regular trips to the premises. The trips began in 2006

and continue to this day. In these field trips, the team performed measurements, empirical analyses, and *in loco* observations, while also gathering data and photographic evidence.

The gathered data were taken to the main office of the Center for Geoenvironmental Analysis (NAGEA), in the Federal University of Juiz de Fora (UFJF). The data were then analyzed by means of reports and maps using ArcGIS software, version 10.2.1.

Results and discussion

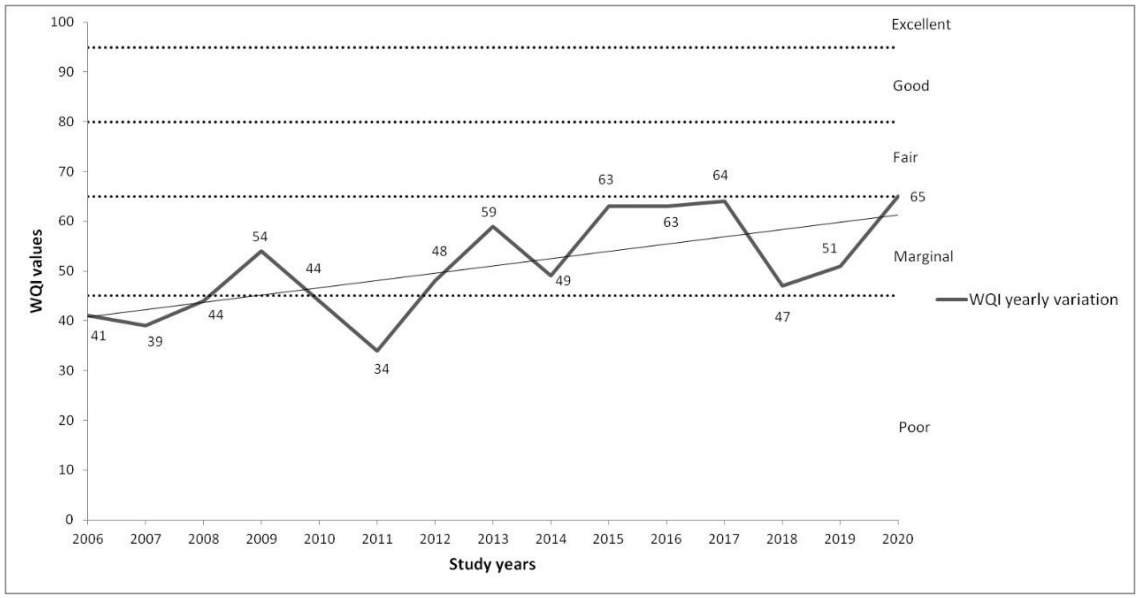
Water quality analysis

The graph in Figure 2 is the result of research carried out by Rocha *et al.* (2019a), updated in 2020 by the authors of this paper. It illustrates in an easily understandable manner the evolution of WQI in the waters of São Pedro Dam throughout the 15 years of study (2006–2020). The graph shows the evolution of the index from “poor” to “marginal.” It also marks the transition to “fair” in 2020, only because of the drop in traffic volume along BR-040 and the pause in construction caused by the COVID-19 pandemic.

These results suggest that the quality of this water supply source was compromised, as “marginal” class indicates frequent noncompliance of water quality parameters with water body classification criteria. Even worse is the “poor” class, which signals constant changes in water quality. Therefore, use of this water for human supply is highly unrecommended (AMARO, 2009; ANA, 2012)

Figure 2

WQI evolution graph throughout the 15 years of study in São Pedro Dam reservoir



Source: Rocha *et al.* (2019); the authors (2022).

According to research carried out by the authors of this paper, during the entire period of study (2006 to 2017), the worst WQI values were in the years 2006, 2007, 2008, 2010, and 2011. The negative peak, that is, the worst WQI of all years, was registered in 2011. The authors link this unfavorable result to the widening of BR-040, in 2007, and the construction of BR-440, in 2010 and 2011. Earth movement operations possibly led to the carrying of solid matter and contaminants to the water body (ROCHA *et al*., 2019a). The period stretching from 2015 to 2017, which shows the best levels in the dataset, close to "fair," coincides with the pause in construction. Once construction resumed, in 2018, WQI returned to "marginal" and came close to "poor." The interruption in activity caused by the COVID-19 pandemic, in 2020, led to the best value in the dataset (WQI = 65).

Bad-quality public supply water may have several harmful health consequences. Human consumption requires compliance with specific aesthetic, physical, chemical, and microbiological quality standards (SOARES *et al*., 2019).

In addition to the required absence of microorganisms and pathogenic substances, public supply water must also be convincingly reliable in the eyes of its consumers. Even water with physical, chemical, and biological properties that are deemed safe in regards to public health may be rejected due to unpleasant sensorial properties, such as taste, odor, and color (da SILVA & VALENTINI, 2020).

The negative results observed in São Pedro Dam waters influence treatment and distribution processes by increasing difficulty and costs.

The turbidity parameter, for instance, was one of the parameters with greatest noncompliance with criteria set forth in legislation, namely the Ministry of Health Consolidation Ordinance No. 5/2017 (Annex XX), which outlines Brazilian standards for drinking water quality and sets maximum allowed values for numerous water properties (BRASIL, 2017). This ordinance replaced Ministry of Health Ordinance No. 2,914/2011 (BRASIL, 2011).

As turbidity is one of the main parameters associated with transport of matter to a body of water, compromising water quality (LEMOS & MAGALHÃES, 2019), an increase in turbidity may partially—or even fully—compromise conventional water treatment processes, such as filtration and coagulation, thus requiring implementation of pre-treatment and increasing treatment costs (GLUSCZAK, 2018).

The graph in Figure 2 shows an improvement in water quality in São Pedro Dam reservoir from 2012 onwards. This is reflected in the improvement of WQI in the final years of the analysis, as the index went from "poor" to "marginal." However, said result is still far from ideal for a water supply source of this sort. Nonetheless, it attests to the water body's self-purification capacity and its resiliency potential. Rocha *et al*. (2018a) believe that this resiliency may not be sufficient to enable medium- and long-term use of this water for public supply (ROCHA *et al*., 2018a; ROCHA *et al*., 2018b; ROCHA *et al*., 2019a).

According to Freitas (2015), the catchment basin of São Pedro Dam has suffered from the crisis in water resource management procedures, aggravated by the observed reduction in rainfall volume in recent years. The author believes that disorderly settlement, coupled with strong real estate market pressure and widespread cut-and-fill operations, has a direct negative effect on the quality of the water supply source.

Environmental impact in São Pedro Dam

Construction of BR-440 led to the suppression of riparian vegetation. This is shown in the background of Figure 3, made as a result of a December 2010 field trip. Figure 3 also reveals use of heavy machinery, causing soil compaction and hindering water infiltration processes. This affects replenishment of the underground aquifer that adds to the volume flowing into the São Pedro Dam reservoir.

The image also shows the building of a drain canal around the dam. This canal was meant to protect the dam, but it is actually draining water from several springs to a point downstream from the dam. This drained water thus bypasses the reservoir, diminishing its stored water volume.

Figure 3

Suppression of riparian forest, use of heavy machinery, and canal construction, by the banks of São Pedro Dam reservoir, during construction of BR-040

Source: The authors (2022).

The image on the left in Figure 4 indicates that the strip of land intended for permanent preservation, as defined by the Brazilian Forest Code, which should be at least 30 meters

wide, is in fact much narrower—only 5 meters were preserved, or less than 17% of the extension required by law. The image on the right in Figure 4 shows that the embankment of the highway and the drain canal around the dam reservoir led to the "shrinking" of the stretch of riparian forest, depriving the body of water of much-needed protection.

Figure 4

Distance between the banks of São Pedro Dam reservoir and the embankment of BR-440 (left) and suppression of riparian vegetation during the construction of BR-440 (right)

Source: The authors (2022).

Highway operation near conservation areas may also result in water source contamination, due to accidents involving vehicles carrying hazardous materials, heavy metals, oil and grease, solid waste dumped by passersby, as well as other products that may flow directly to the water source as a result of proximity. Said contamination has socio-environmental consequences and effects such as damage to public water supply (BENTO, 2019). The spillage of such substances is fairly common, mainly in developing countries such as Brazil, where the flow of products is remarkably dependent on road transport (SIQUEIRA *et al.*, 2017).

This process is known as diffuse contamination, in which loads of pollutants, residue, and generated sediment, coupled with rainfall and resulting runoff, flow into the body of water intermittently, causing changes to the environment and compromising local ecological functions (SILVA *et al*., 2018).

Man-made changes in Permanent Preservation Areas (PPAs) may compromise water availability, regardless of accidents involving hazardous loads.

Proper maintenance of riverside PPAs by the banks of the Dam reservoir provides a filter-like function against air pollution, mainly for pollutants generated by traffic along the highway, the pyrolysis (burning of fossil fuels) of which generates polycyclic aromatic

hydrocarbons (PAHs). These chemical compounds are cumulative in nature and precipitate near the places where traffic flows through, and it is not possible for them to be filtered out by conventional water treatment plants (JACQUES *et al.,* 2007). As São Pedro Dam water is used by part of the population of Juiz de Fora for public supply, a new problem arises: the accumulation of said compounds in the bodies of the consumers of this water. This may cause medium- and long-term health problems in the population.

Souza (2008) identified high levels of PAHs near BR-040. According to the author, "the surroundings of high-density highways, such as BR-040, are more prone to contamination by pollutants generated in fuel pyrolysis. Scientific literature suggests that PAH concentration tends to drop as samples are collected farther from the highway. PAHs make their way to water systems through deposition of contaminated airborne particulate matter on the water surface, leading to the contamination of the entire water column and the sediment." Soil samples collected 10 m away from BR-040 showed higher concentrations of quantified compounds, such as phenanthrene (0.024 µg.g-1, in dry weight), fluoranthene (0.027), and pyrene (0.040). However, sediment in the Dam reservoir was PAH-free, certainly due to compliance with APP width requirements and due to the presence of riparian forest (ROCHA, 2010).

The "sponge effect" is another important function of Permanent Preservation Areas and riparian forest. Sponge effect is the buildup of water in soil and in the roots of riparian vegetation. This water can be released in the dry season, increasing the volume of available water and preventing significant drops in aquifer and dam reservoir levels.

Therefore, the environmental effects of highway construction near São Pedro Dam reservoir are numerous and of a considerable magnitude. Earthworks in the first stage of BR-440 construction caused the filling of a water spring with land. These operations resulted in the carrying of sediment to the water source, as documented in Figure 5. Aggradation reduces the Dam reservoir's storage capacity as it raises its bottom level.

Figure 5

Spring filled with land in the banks of São Pedro Dam reservoir as a result of earthworks during construction of BR-440

Source: The authors (2022).

So far, there is no official record of any reforestation projects or dredging operations in São Pedro Dam reservoir by local government agencies.

Figure 6 is a photo taken during the dry season, in August 2016. It shows the improperly built canal collecting considerable levels of water from local springs. The result is that springs play a diminishing role in the filling of São Pedro Dam reservoir. Observation of the canal's path shows that the water that flows through it is discharged in São Pedro Creek and used in the purification of practically raw wastewater. That said, there is a remarkable waste of the high-quality water provided by the local springs.

Figure 6

Presence of quality water, flowing from springs through the canal, during dry season

Source: The authors (2022).

The photos in Figure 7, also taken in August 2016 (dry season), show that there is plenty of water coming from the springs. This water, however, flows into São Pedro Creek, downstream from the dam, instead of flowing into the water supply source.

Figure 7

Spring water being wasted due to incorrect construction of the canal

Source: The authors (2022).

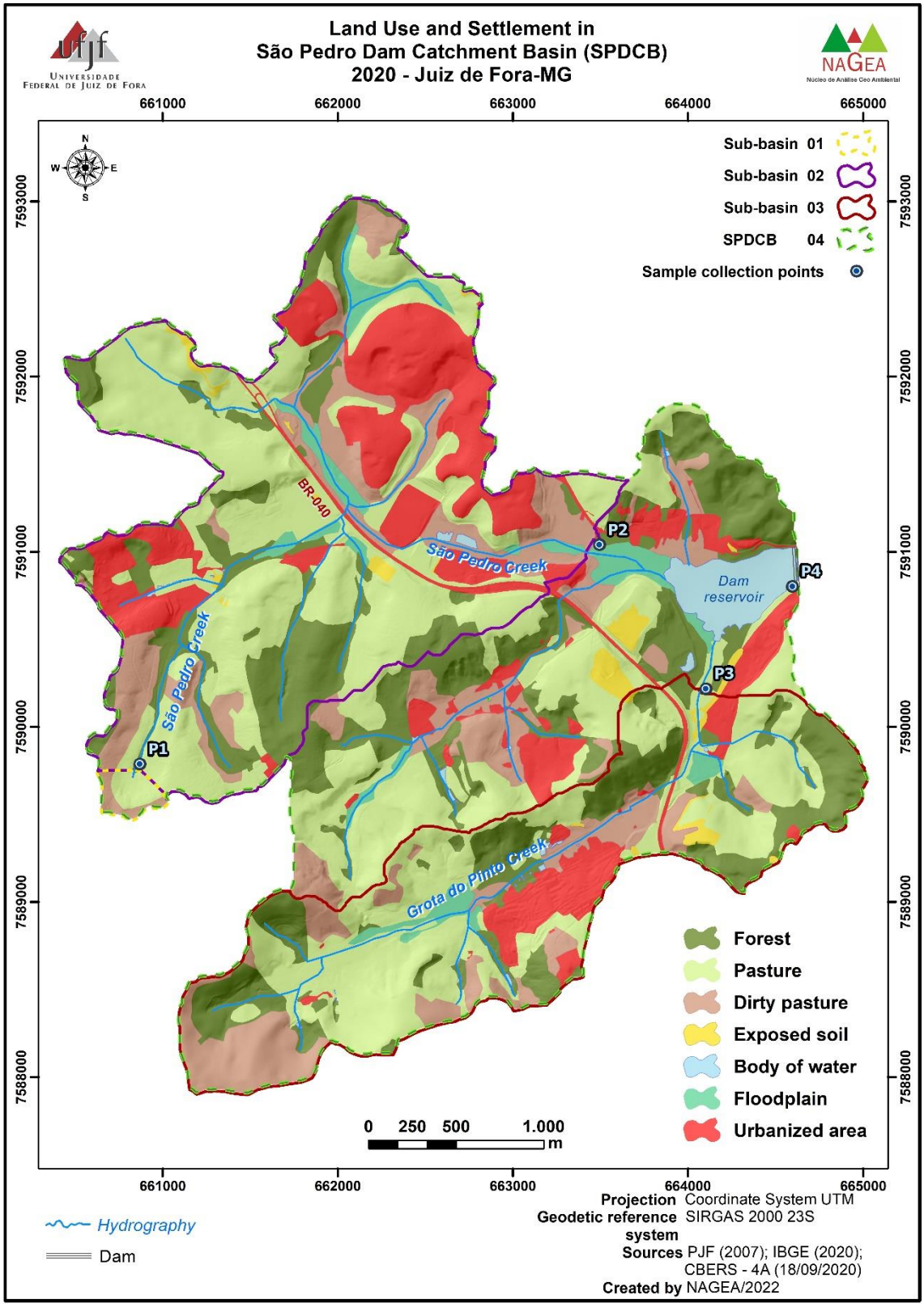
Water springs are essential elements in the hydrologic system of drainage basins, as they help fill and maintain water levels in supply sources. Also, it is through springs that groundwater transitions to surface water. In terms of public supply, springs are the most economically feasible alternative, as the costs of spring water treatment are considerably lower. Thus, proper preservation of water springs is essential to conservation of quality and preservation of the environment (SILVA *et al*., 2016; SILVEIRA, SANTOS & SOUZA, 2019).

Figures 6 and 7 are evidence of the negative impact of disorderly settlement in the environment. Riparian vegetation, previously suppressed as part of BR-440 construction, started to recover—albeit slowly—according to data collected during an August 2016 field trip, after road construction was suspended, boosting the protection of São Pedro Dam reservoir's banks.

Finally, it is also worth mentioning that São Pedro Dam reservoir is filled with water from two main tributaries, depicted in Figure 8: São Pedro Creek (to the left) and Grota do Pinto Creek (to the right). These two creeks have a combined median flow of about 350 liters of water per second, while São Pedro Water Treatment Plant has a treatment capacity of 140 liters/second only. The next stretch of road, as indicated by the red strip between points P4 and P3, will be built over patches of forest that protect the body of water and over Grota do Pinto Creek (P3). This creek alone provides the dam reservoir with a median flow of 150 liters of water/second. This leads to the conclusion that it is possible to double the capacity of São Pedro Water Treatment Plant, enabling it to supply a larger share of the population of the city of Juiz de Fora.

Figure 8

Map of land use and cover in the São Pedro Dam basin, in Juiz de Fora, Minas Gerais



Source: The authors (2022).

Analysis of the map showing land use and cover in the São Pedro Dam catchment basin clearly indicates seven classes of land cover: forest, pasture, dirty pasture, exposed soil, body of water, floodplain, and urban area. The dam reservoir is shown in blue, along with the entire hydrographic network that forms its basin, the area of influence of which is remarkable. There is a direct influence of land cover types within the drainage basin's borders over the quality and the quantity of water. In their research, Casquin (2016), De Mello (2020), Rocha *et al.* (2019b), and Rocha *et al*. (2020) show the correlations and the effects of each type of land use and cover in water quality, highlighting the negative effects of pastures and urban areas.

Remaining vegetation in the basin is shown in dark green. Figure 8 shows that this vegetation accounts only for a small fraction of the land, in comparison with other classes, mainly around the Dam.

The red areas in the south and north parts of the map respectively indicate the planned neighborhoods of Passos Del Rey, by Grota do Pinto Creek, and Alphaville, by São Pedro Creek. The sum of these two areas is almost equal to the total area of remaining patches of forest in the whole catchment basin of São Pedro Dam, as shown in Figure 8.

Figure 9 shows the eastern part of Figure 8 in detail, upstream from point P3, which is the sub-basin of Grota do Pinto Creek. This creek was channelized to make way for the intersection of BR-440 and BR-040 highways.

Figure 9

Intersection of BR-440 and BR-040 and channelization of Grota do Pinto Creek

Source: Tribuna de Minas (2019).

Unfortunately, neither city authorities, nor the Municipal Sanitation Company (CESAMA) could stop Supplementary Law No. 082/2018, which "outlines the Urban and Territorial Development Policy, the Municipal System of Territorial Planning, and the revision of the master plan of Juiz de Fora as outlined in the Federal Constitution and the City Statute, and sets forth other provisions," from excluding the São Pedro Dam basin from the Macro-area of Environmental Interest and Water Source Preservation (MA3), in its Article 66:

> *Art. 66. The Macro-area of Environmental Interest and Water Source Preservation (MA3) encompasses the parts of territory corresponding to the catchment basins of the public water supply sources* ***Dr. João Penido Dam reservoir, Espírito Santo Creek, and Estiva Creek basin...***
> *SECTION III*
> *On the Macro-area of Environmental Interest and Water Source Preservation (MA3)*
> *Art. 67. The specific aims of the Macro-area of Environmental Interest and Water Source Preservation (MA3) are:*

I - to recover, preserve, and protect public water supply sources in the city of Juiz de Fora;
II - to recover, preserve, and protect drainage basins with the potential to serve as future public water supply sources in the city of Juiz de Fora;
III - to spur growth of forest areas;
IV - to contain urban sprawl;
V - to curb effective or potentially polluting uses and activities, as outlined in DN COPAM nº 74/2004 and its resulting changes (JUIZ DE FORA, 2018).

In this case, public officials left this water source to the mercy of real estate speculation, leading to the approval of the Estrela do Lago neighborhood project, which lies in the very sub-basins of Grota do Pinto Creek and uses its water in a so-called “small beach,” according to the way that this project’s land plots are advertised (Figure 10).

It is noteworthy that such a complex project, which leads to interference in Permanent Preservation Areas, suppression of riparian vegetation, and channelization of creeks, and which is located in the sub-basin of a tributary to a functioning public water supply source, was processed from 09-08-2019 to 15-06-2020 (in less than a year), having its license issued by the city government of Juiz de Fora in the latter date. The first planned neighborhood with a private beach in Juiz de Fora sold out its land plots in only a few hours. This sets a precedent for other planned neighborhood projects in the vicinity of this public water source and of other sources that supply the city. In a time when water is a highly valuable resource, it is questionable that public officials fail to defend public and collective interest by authorizing a project that does not match the permitted cases of construction in Permanent Preservation Areas, as defined by law. According to Figure 10, earthworks authorized by the city government of Juiz de Fora resulted in the reclamation of floodplains in the vicinity of the intersection depicted in Figure 9, thereby reducing the recharge areas of the Dam reservoir. The increase in sediment generation will boost aggradation of the water source and reduce its storage capacity.

Figure 10

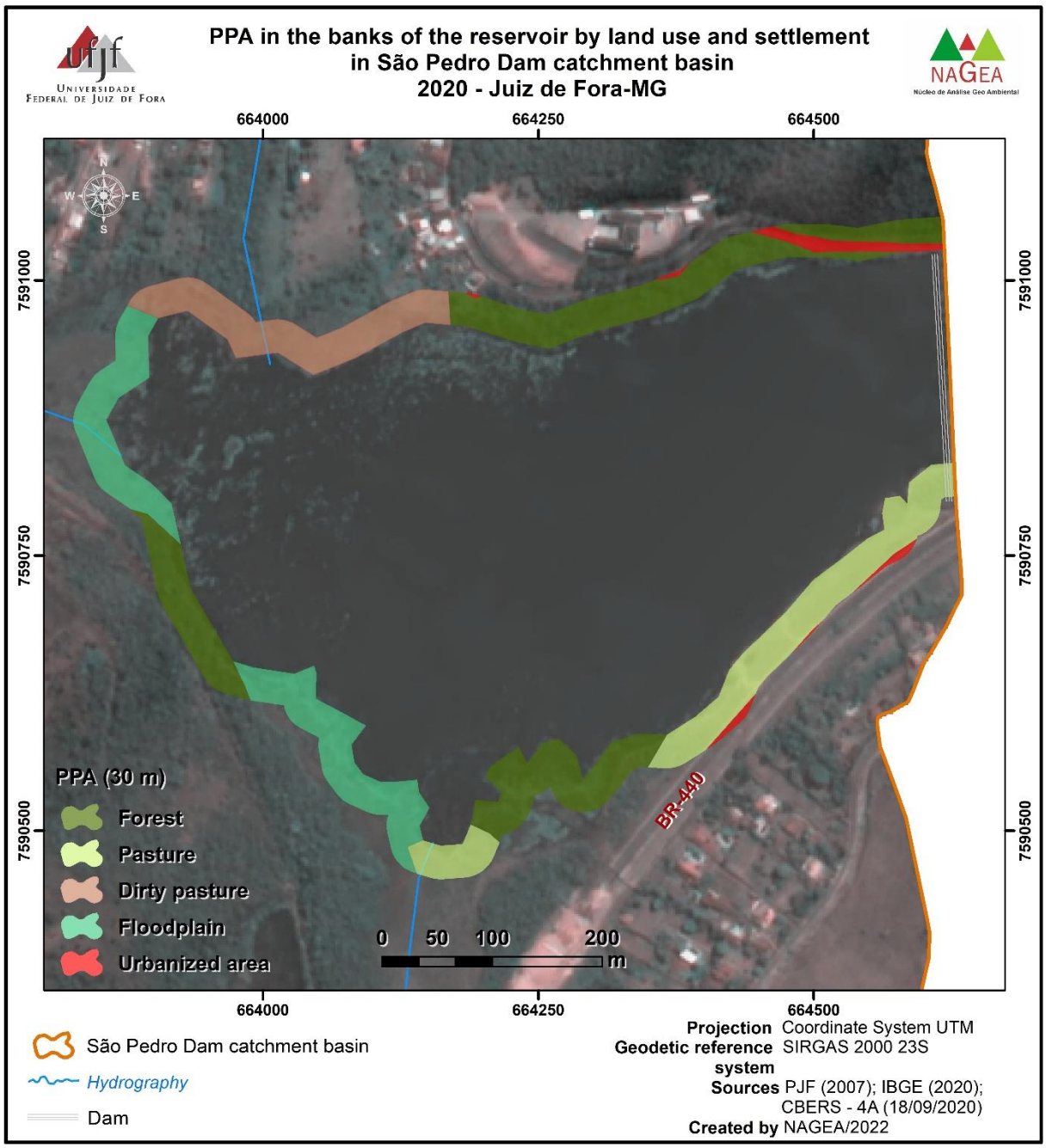
Estrela do Lago planned neighborhood, in the Grota do Pinto Creek basin, near São Pedro Dam

Source: Google Earth (2022).

It is possible to measure the impact in the water source by taking into account limnological and land-use variables in the PPAs. Figure 11 indicates conflicting land use in PPAs situated in the catchment basin of São Pedro Dam. Authors like Tundisi and Tundisi (2010) point out that removal of vegetation in sensitive areas causes often irreparable damage, increasing operational costs of water treatment systems due to the rise in water source aggradation.

Figure 11

PPA map of the banks of São Pedro Dam reservoir



Source: The authors (2022).

The aforementioned figure shows that the suppression and the consequent loss of forested areas, caused by construction works, happened precisely in the PPAs situated in the banks of the reservoir, in order to make way for machinery used in the construction of BR-440. It is also observed that, even after a period of several years during which vegetation was left untouched, the PPAs in the banks (riparian forest) have not recovered to levels which would be sufficient to have a positive impact on the water source. Similar processes are observed in

other water sources in the city, such as Dr. João Penido Dam reservoir, for which the city has issued specific legislation, and where there is only 15% of forest in riparian PPAs. In 2017, urban areas accounted for 25% of this PPA. This is not desirable for a water supply source (Rocha et al., 2019c).

The repeal of CONAMA Resolutions No. 302/2002 and No. 303/2002 follows the same logic at national level, leaving our water supply reservoirs, sandbanks, and mangroves to the mercy of disorderly urban expansion. What do public officials intend to achieve with such measures? Where is our ecologically balanced environment, as outlined in Article 225 of our Constitution?

These public officials have failed to comply with one of the Principles of Environmental Law, the Principle of Retrocession Prohibition, which aims to safeguard the progress made until now, in order to avoid or curb environmental degradation (PRIEUR, 2012).

Conclusion

Data gathered in this study lead to the conclusion that both construction and operation of BR-040 and BR-440 highways, in the banks of São Pedro Dam reservoir, coupled with established planned neighborhoods, pose evident risks to the qualitative and quantitative properties of the water in the local public supply source, in the short, medium and long term.

WQI measurements in other studies carried out in the same water supply source point to a drop in water quality in the period of BR-040 expansion and BR-440 construction. This emphasizes the influence of these events in the composition of the index and the damage done to the body of water. The environmental improvement caused by the pause in BR-440 construction is another evidence of said influence, attesting to the recovery of riparian forest and the resiliency of the water source.

BR-440 construction resulted in the aggradation, compaction, and contamination of soil, the filling of water springs with land, and the diversion of water to points situated downstream from the dam reservoir, impeding its contribution to reservoir levels. It also means that high-quality water, which could be used in the supply of the population of the city of Juiz de Fora, is instead used in the purification of virtually raw wastewater, further downstream, in the São Pedro Creek.

Even though the dam reservoir has self-purification properties, as shown by the improvement in WQI after 2011 (from “poor” to “marginal”), this situation is not only far from ideal, but it also does not comply with legal quality standards, especially those applicable to high-quality water usage and Class 1 water bodies. The improvement observed in 2015–2017 coincides with the halt in highway construction. The new WQI high in 2020, caused by yet

another interruption in roadworks due to the COVID-19 pandemic, attests to the sensitivity of this index to man-made impact.

This study reveals the degree of contribution provided by the dam reservoir's tributaries, Grota do Pinto Creek and São Pedro Creek, that are capable of supporting a twofold increase in the volume of water treated by the São Pedro Water Treatment Plant, while keeping downstream ecological flow. This would decrease the risk of supply cuts and rationing, which have been frequently observed in the city in the past few years, during the dry season. The next step in BR-440 construction is a stretch of road set to be built over patches of forest that protect the body of water, above Grota do Pinto Creek (which is currently undergoing channelization), to make way for the intersection of BR-040 and BR-440. This may have serious implications in the availability of water in the creek. Constant traffic and occasional accidents involving hazardous loads may compromise medium- and long-term use of this water.

Greater hydrologic dependence on the waters of Chapeú D´Uvas Dam reservoir, which is situated in land that belongs to other municipalities, is a complex matter, as it is harder to manage environmental assets beyond the borders of Juiz de Fora, not to mention the diverse uses of this water, some of which may not fit water quality criteria for public supply.

The land use and cover map of the catchment basin and the PPAs by the banks of the reservoir shows that there is only a small fraction of remaining forest in São Pedro Dam's surroundings. Real estate speculation also has a notable effect in Juiz de Fora, as it leads to the "legalized" settlement of areas which should be protected and preserved, as evidenced by the construction of highways and high-class planned neighborhoods. Was there any environmental compensation, at least? It is clear that public officials neglect this important source of water and leave it unprotected from real estate speculation.

So far, there is no official record of any reforestation or remediation project in this water supply point by the very government agencies whose responsibility is to manage and curb these land-use conflicts. What about the retrieval and treatment of wastewater in the premises? What about dredging operations, so the reservoir's storage capacity is increased and downstream floods are reduced? What is seen in practice, however, is the construction of highways and planned neighborhoods in floodplains and recharge areas, contrary to the sustainability sought by mankind.

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